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ASD PHASE II REPORT 7-848 (II)
FEBRUARY 1962

HIGH ENERGY IMPACT FORMING PROGRAM

PROTOTYPE DESIGN PARAMETERS STUDY PROGRAM

ROBERT A. KASER
FRANK A. STRATTON

ADVANCED PRODUCTS DEPARTMENT
GENERAL DYNAMICS CORPORATION

CONTRACT: AF 33(600)-43035
ASD PROJECT 7-848

PHASE II REPORT
8 AUGUST 1961 - 8 JANUARY 1962

Test procedures to determine the basic parameters of the prototype high energy rate rubber pad sheet metal forming machine to be constructed in this program are described. Results of tests of the effects of energy and velocity on sheet metal formability and design parameters of the prototype machine are given.

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

ABSTRACT - SUMMARY

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HIGH ENERGY IMPACT FORMING PROGRAM
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Robert A. Kaser - Frank A. Stratton

Advanced Products Department
GENERAL DYNAMICS CORPORATION

Test procedures to determine the basic parameters of the prototype high energy rate rubber pad sheet metal forming machine to be constructed in this program are described. Results of tests of the effects of energy and velocity on sheet metal formability and design parameters of the prototype machine are given.

Existing high energy rate metal forming machines were used with test tooling and blanks to investigate the effects of energies of 64,500 to 565,000 inch pounds and velocities of 216 to 622 inches per second on the formability of aluminum and stainless steel alloys formed at intervals of 1.3 to 7.75 milliseconds.

As energy was increased an improvement in formability was achieved up to a certain level. Further increases in energy per unit area of the rubber pad and the resulting increases in rubber pressure did not result in conclusive improvements in sheet metal formability. The investigation demonstrated the extremely accurate control of blow energy inherent in the pneumatically operated high energy rate metal forming machine.

At a constant energy level, impact velocity was independently varied by changing the mass of the moving ram. When impact velocity was varied from 404 to 622 inches per second, no significant differences in formability could be detected.

It is felt that improvement in sheet metal formability at the velocity range investigated is the result of the higher rubber forming pressures. High rubber forming pressures are easily achievable using the high velocity gas-driven actuator principle.

Using the information obtained, the basic design parameters for the prototype machine were established.

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NOTICES

FOREWORD

This Phase II Report covers the work performed under Contract AF 33(600)-43035 during the period from 8 August 1961 through 8 January 1962. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Air Force.

This contract was awarded to the Advanced Products Department of the General Dynamics Corporation and is administered under the technical direction of Mr. B. B. Waters, ASRCTF, Wright-Patterson Air Force Base, Ohio.

This project is under the direction of Mr. James A. Kline, Manager, Mechanical Research and Development, Advanced Products Department, General Dynamics Corporation.

The task called for in Phase II of the contract was a prototype design parameters study program. This report contains the description of the test programs and their results as well as the preliminary basic design parameters of the prototype rubber pad high energy metal forming machine to be constructed under the following phases of this contract. An outline of the work to be performed in the next phase of the contract is also included.

Approved by:

James A. Kline

James A. Kline, Manager,
Mechanical Research
and Development

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INTRODUCTION

The work carried out in this second phase of the overall program was divided into two related portions.

The first portion consisted of study and testing planned to establish the basic parameters affecting the design of the prototype machine to be constructed and tested in the following phases of the program.

Using an existing high energy rate metal forming machine, test programs were conducted to obtain needed information for the energy, velocity and rubber pressure capabilities of the prototype.

The response of typical rubber pad sheet metal forming tooling to deformation was investigated both statically and dynamically. The test program was planned to determine the tooling response to an impact blow, to determine resulting rubber pressure as a function of energy variation, and to determine the effect of change in blow energy on formability of sheet metals. Using a constant energy level in part of the test program, a series of tests were conducted to determine the velocity capability required.

The second portion of the basic task in this phase was carried out simultaneously with the test programs in the first portion. This consisted of study and testing to gain knowledge important for the design and use of the prototype machine. The optimum operating rate, cycle time, safety hazards, alternate energy sources, alternate elastomers and other factors were investigated.

CONCLUSIONS

The test programs achieved their purpose in providing information for the basic design parameters of the prototype high energy rate rubber pad sheet metal forming machine to be designed and constructed as part of the overall program.

The following conclusions and recommendations are based on the data obtained in the series of test programs.

The prototype machine should have a maximum energy level of 2,400,000 inch pounds to yield a maximum rubber pad pressure of 20,000 psi.

The relative velocity between the ram and bolster at this maximum energy will be 825 inches per second maximum.

The 20,000 psi operating level establishes an ultimate capacity and it is felt that normal usage of the prototype machine will be at 50% of its capacity, i.e., 1,200,000 inch pounds yielding 10,000 psi rubber pad pressure.

The relative velocity between ram and bolster at this reduced energy will be 600 inches per second.

The ability to generate pressures up to 20,000 psi will make this prototype machine extremely versatile and it will be capable of forming much heavier gauges than those formed in the tests.

Existing equipment using the rubber pad process has determined a "conventional" location for the rubber pad and tooling. Because the test programs were carried out on a horizontal machine, it was not possible to investigate alternative locations.

It is therefore necessary to make a complete evaluation of the optimum location for the rubber pad and tooling, based on production requirements. The results of this evaluation may require the inversion of the prototype machine from the original proposed position, and a design study of the structure required to support this machine configuration.

TENTATIVE MACHINE SPECIFICATIONS

Maximum Energy at 2000 psig	2,400,000 inch pounds
Maximum Stroke	15 inches
Maximum Impact Velocity	825 inches per second
Ram Weight - Less Tooling	3,000 pounds
Rubber Pad Diameter	24 inches
Rubber Pad Thickness	12 inches
Cycle Time	15 seconds
Dwell Time of Tooling - Approximately	0.5 seconds
Weight of Machine - Approximately	50,000 pounds
Floor Reaction - Dynamic	60,000 pounds
Weight of Pump Console	5,000 pounds
Shipping Weight - Approximately	70,000 pounds
Main Power - Pumping Unit	50 Horsepower 440 Volt - 3 Phase
Compressor Power	5 Horsepower 440 Volt - 3 Phase

Auxiliary Power - Control Console	110 Volt
Recommended Floor Area	16 feet x 8 feet 128 square feet

EFFECT OF ENERGY VARIATION

At the energy levels used in the test program, formability was not substantially improved at energy levels above 166,000 inch pounds, corresponding to rubber pressures in excess of 5,895 psi.

The effects of energy variation on formability are best shown by the shrink flanges formed from the .060" thick, 2024-0 aluminum alloy test blanks. These test blanks were formed at six energy levels and these levels, with the corresponding rubber pressures, and the values of h/t and h/R for the 3" and 4" radii are shown on Table 1.

In a report on theoretical formability (5), the values of h/t and h/R were plotted on logarithmic graphs and a series of formability envelopes given for a number of materials. The formability envelope for 2024-0 aluminum alloy is shown on Graph No. 17 with the values obtained from this test program.

The physical appearance of the shrink flanges formed in the test program is shown on Figure 1 with the corresponding rubber pressures indicated for each blank. Examination of Figure 4 will show the locations of the 3" and 4" radii used for evaluation.

In the case of Blank ACH-27, formed at 67,700 inch pounds of energy, and a corresponding rubber pressure of 765 psi, the flanges are not completely formed. The rubber did not fill the space around the form block (non-fill) when this blank was formed. Examination of the table and graph show that the values of h/t and h/R are relatively low for both the 3" and 4" radii although lying above the formability envelope determined by another (5) series of tests.

When the energy was increased to 166,000 inch pounds, the rubber pressure increased to 5,895 psi and the formability improved as shown in the photograph and the tabulated results. The formability over the 3" radius was improved to a greater extent than over the 4" radius and this was noticed in the remaining blanks formed at increasing energy levels and rubber pressures.

Graphs 18 through 23 have energy, rubber pressure, springback and formability measurement h/t plotted for the shrink and stretch flanges formed in the test program. Difficulty was experienced with tearing in the .060" stainless steel stretch flanges and formability values were not available for plotting in some of the graphs, although springback was included where it could be measured.

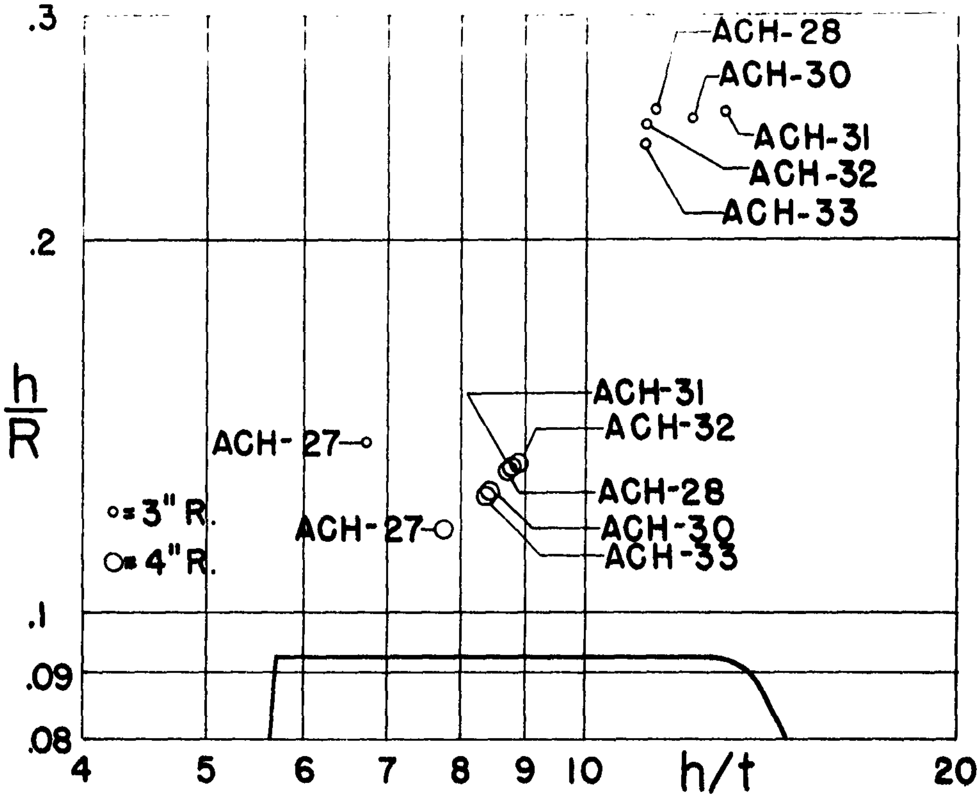
TABLE 1

.060 ALUMINUM SHRINK FLANGES - EFFECT OF ENERGY VARIATION

Blank No.	Energy, inch lbs.	Rubber Pressure	3" radius h/t	3" radius h/R	4" radius h/t	4" radius h/R
ACH-27	67,700	765 psi	6.79	.138	7.70	.117
ACH-28	166,000	5,895 psi	12.17	.254	8.70	.131
ACH-30	262,500	10,767 psi	12.42	.250	8.35	.126
ACH-31	365,300	13,319 psi	12.58	.252	8.65	.130
ACH-32	465,000	15,363 psi	12.32	.246	8.77	.132
ACH-33	565,000	17,909 psi	12.29	.245	8.28	.124

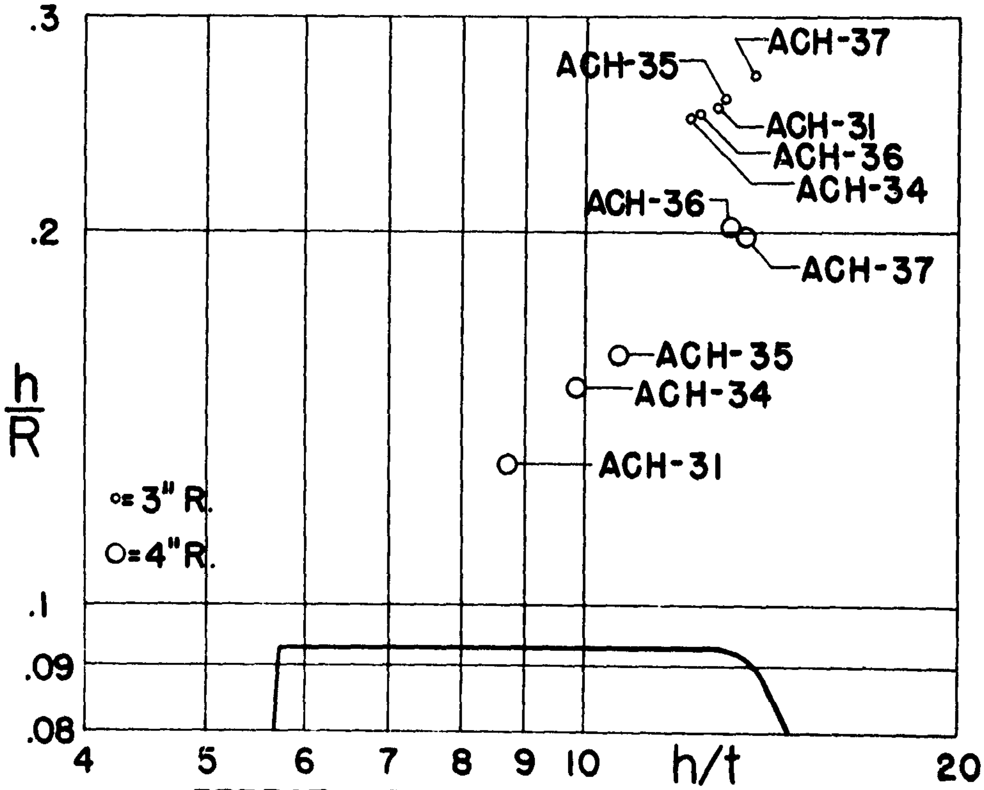
.060" ALUMINUM SHRINK FLANGES - EFFECT OF VELOCITY VARIATION

Blank No.	Energy, inch lbs.	Velocity, inches/sec.	3" radius h/t	3" radius h/R	4" radius h/t	4" radius h/R
ACH-37	365,300	404	13.57	.276	13.04	.199
ACH-36	365,300	430	12.31	.246	13.88	.201
ACH-31	365,300	452	12.58	.252	8.65	.130
ACH-34	365,300	540	12.08	.246	9.83	.150
ACH-35	365,300	622	12.75	.256	10.58	.159



EFFECT OF ENERGY CHANGES

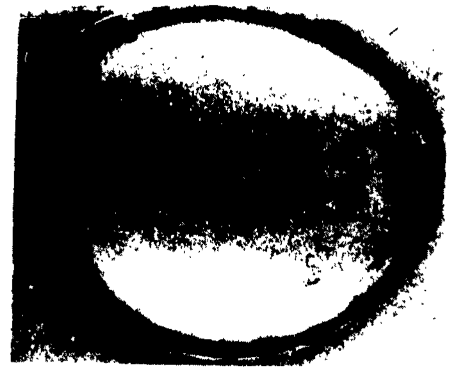
.060" ALUMINUM SHRINK FLANGES - BOTH GRAPHS



EFFECT OF VELOCITY CHANGES

GRAPH No. 17

ACH-27 765 PSI.

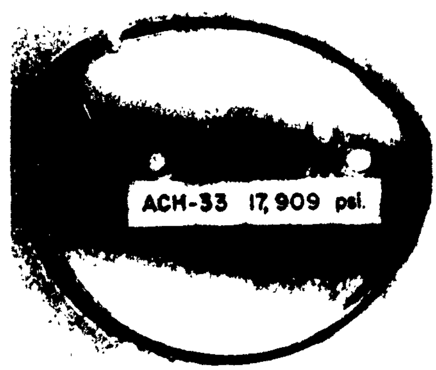


ACH-28 5,895 PSI.

ACH-30 10,767 PSI.

ACH-31 13,319 PSI.

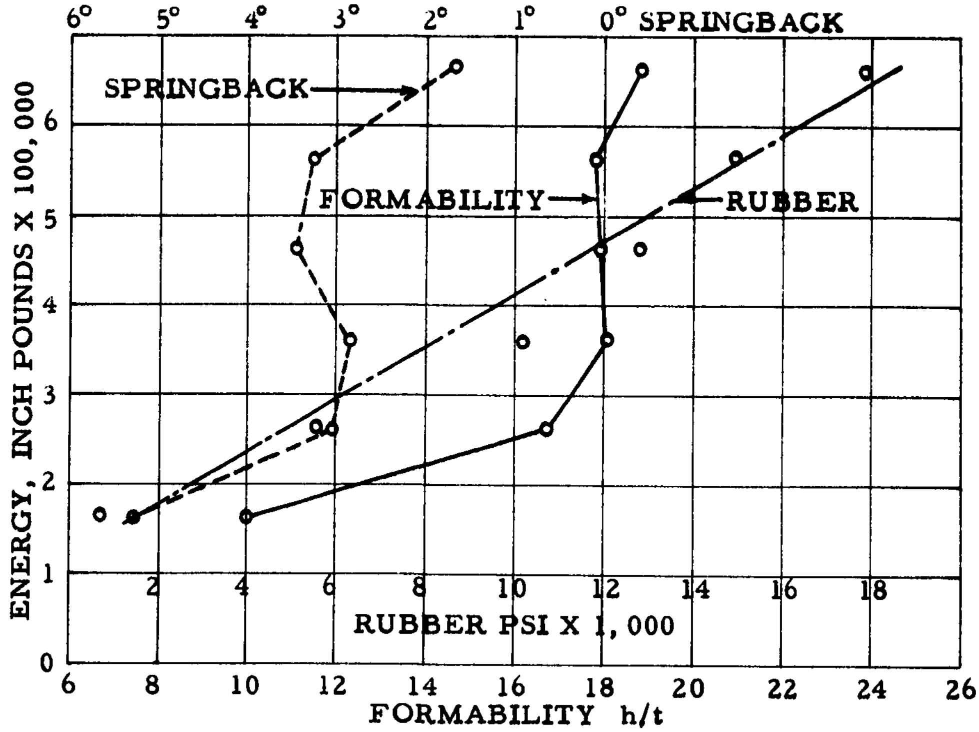
ACH-32 15,363 PSI.



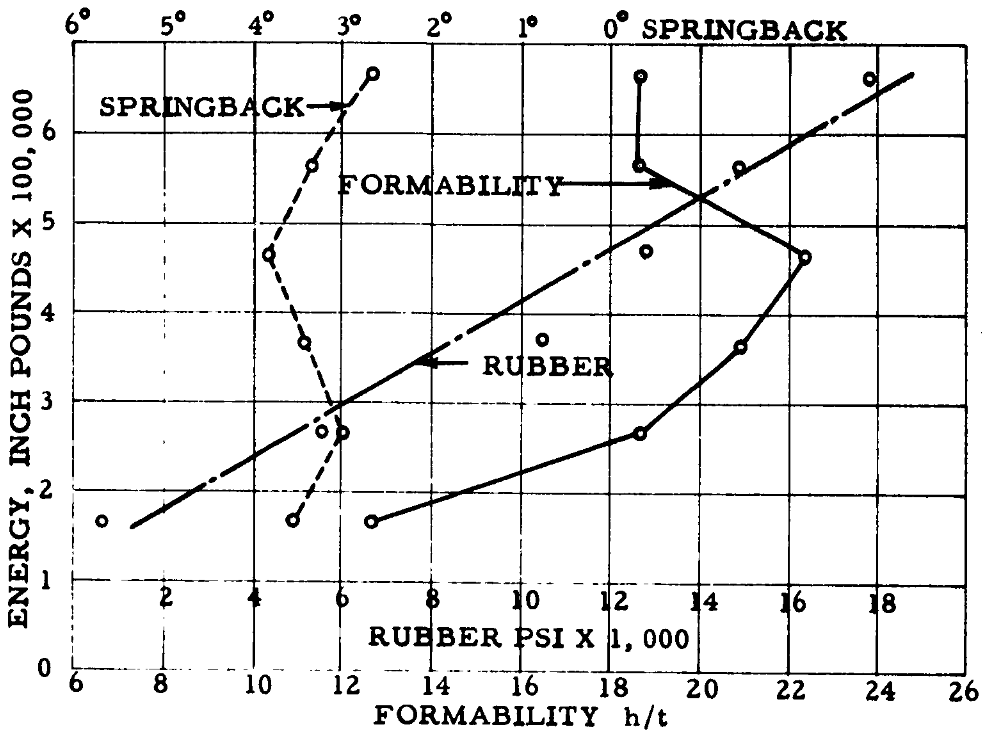
ACH-33 17,909 PSI.

EFFECT OF ENERGY CHANGES
(RUBBER PRESSURE, PSI)

FIGURE 1

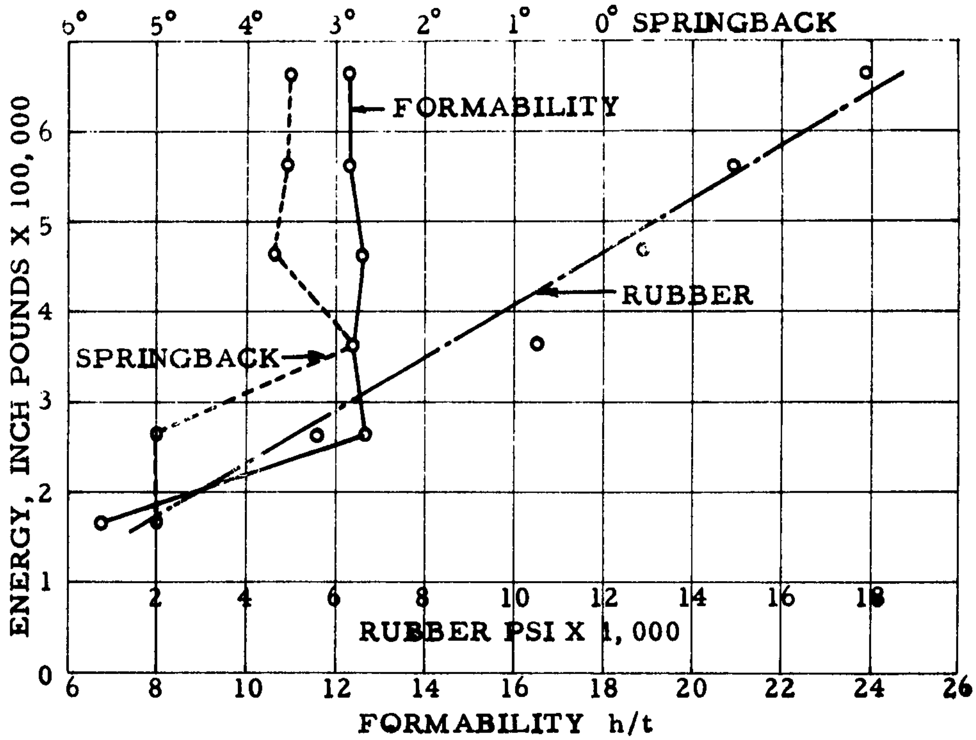


.032" ALUMINUM SHRINK FLANGES, 3" RADIUS

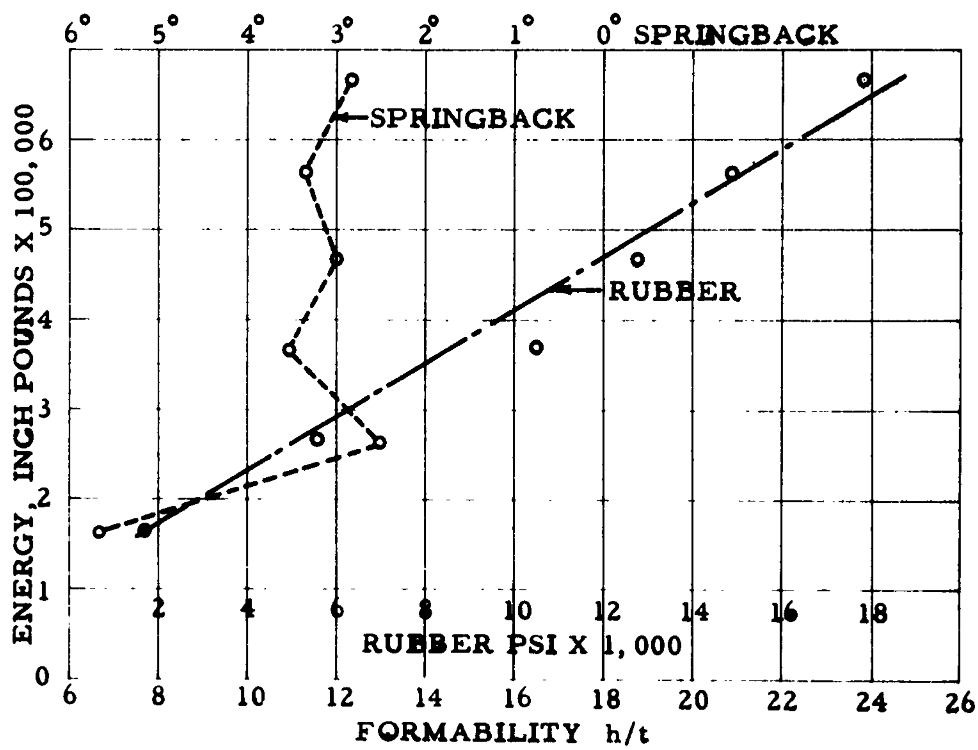


.032" ALUMINUM SHRINK FLANGES, 4" RADIUS

GRAPH No. 18

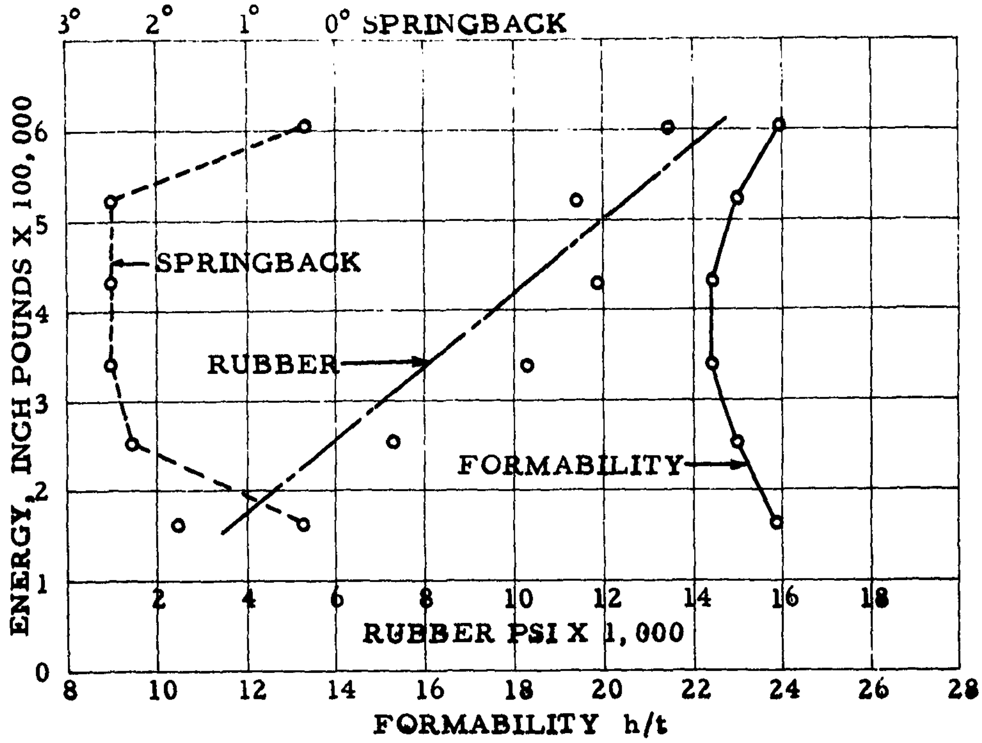


.060" ALUMINUM SHRINK FLANGES, 3" RADIUS

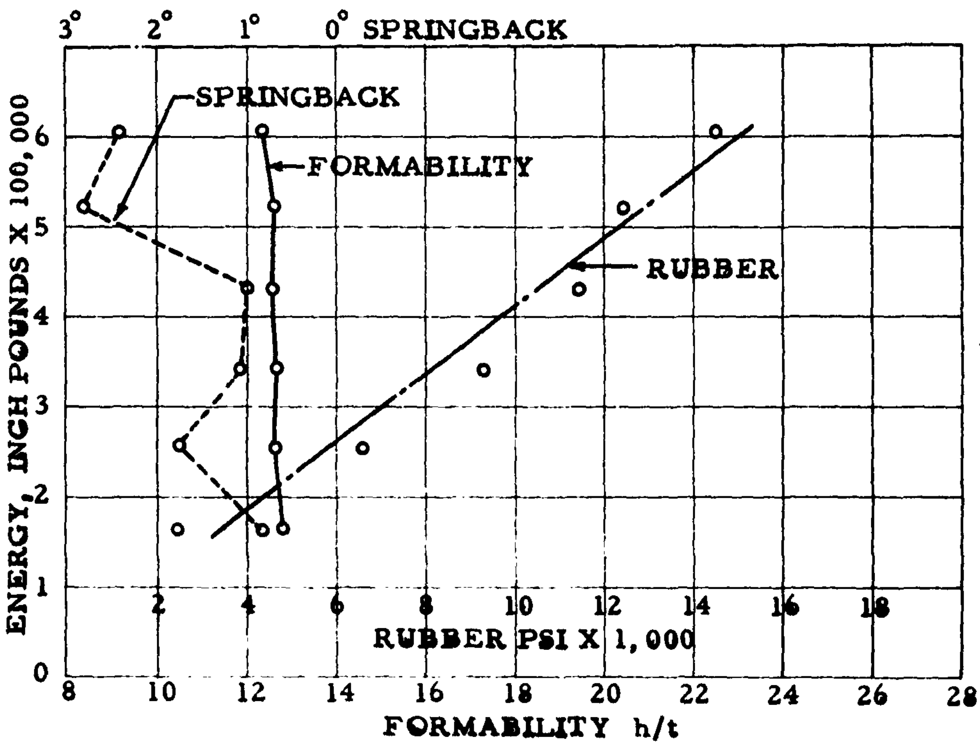


.060" ALUMINUM SHRINK FLANGES, 4" RADIUS

GRAPH No. 19

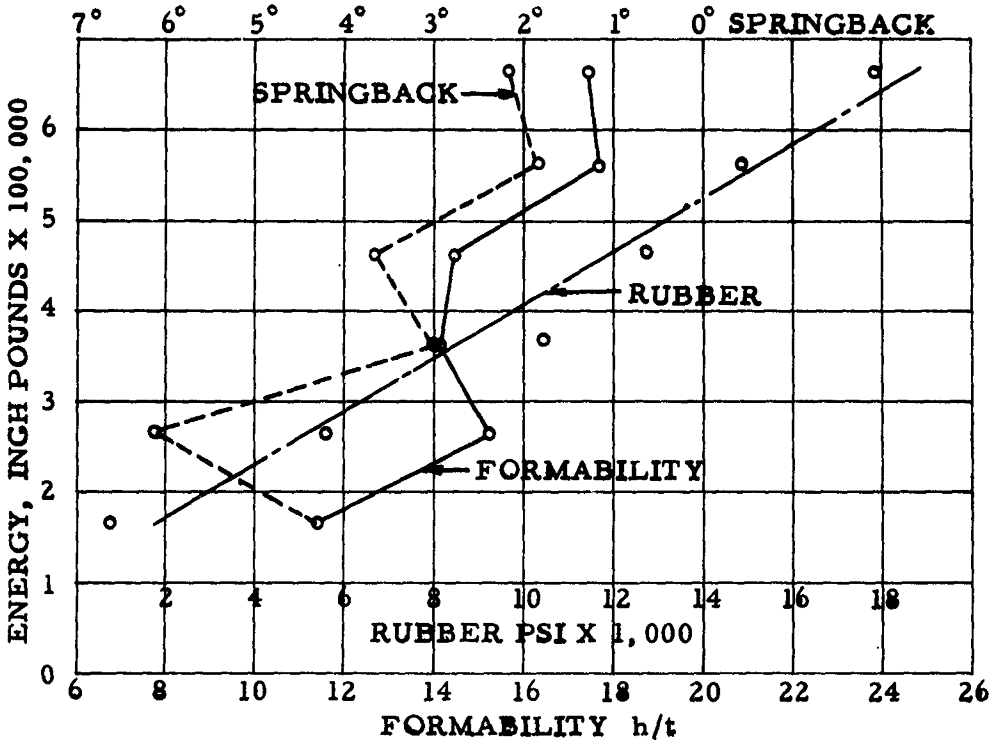


.032" ALUMINUM STRETCH FLANGES

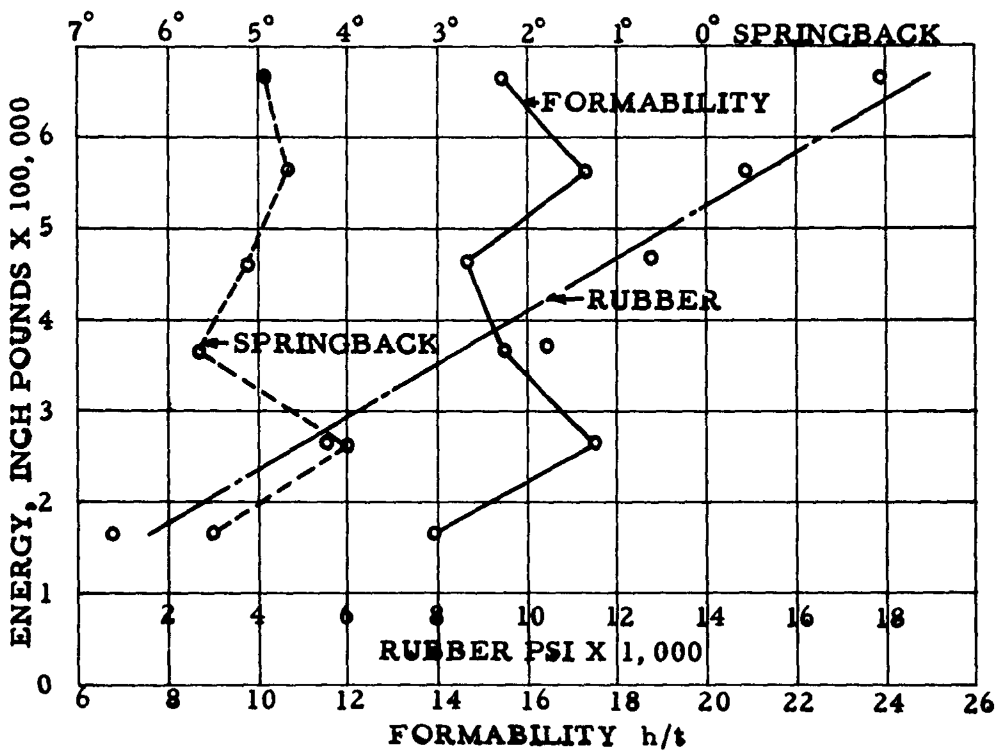


.060" ALUMINUM STRETCH FLANGES

GRAPH No. 20

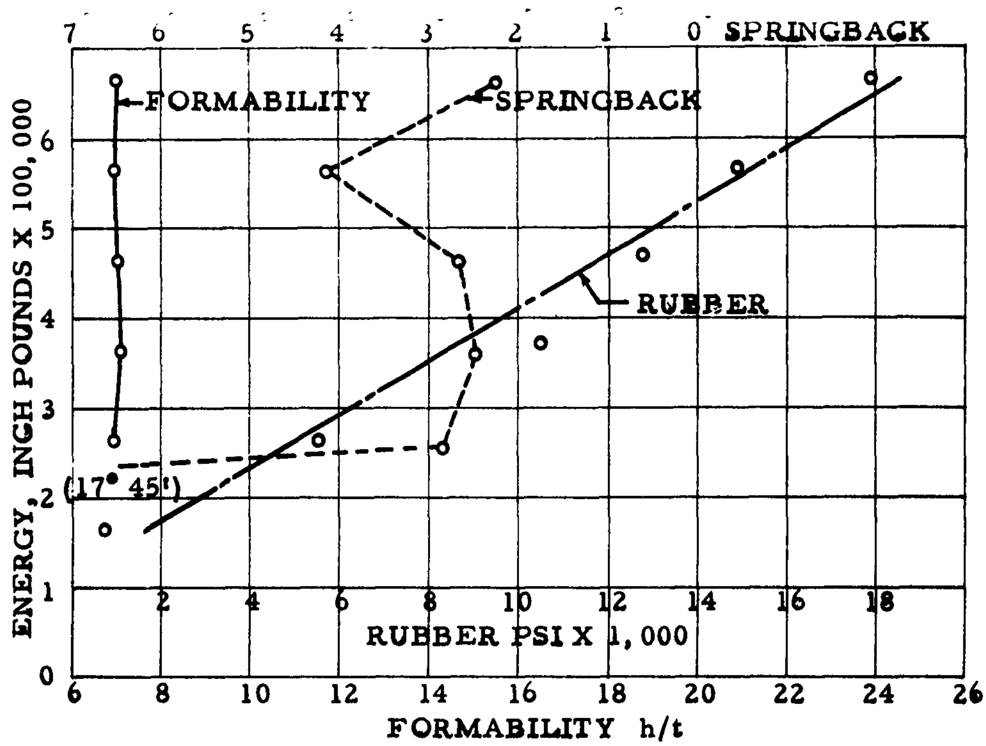


.0275" STAINLESS STEEL SHRINK FLANGES, 3" RADIUS

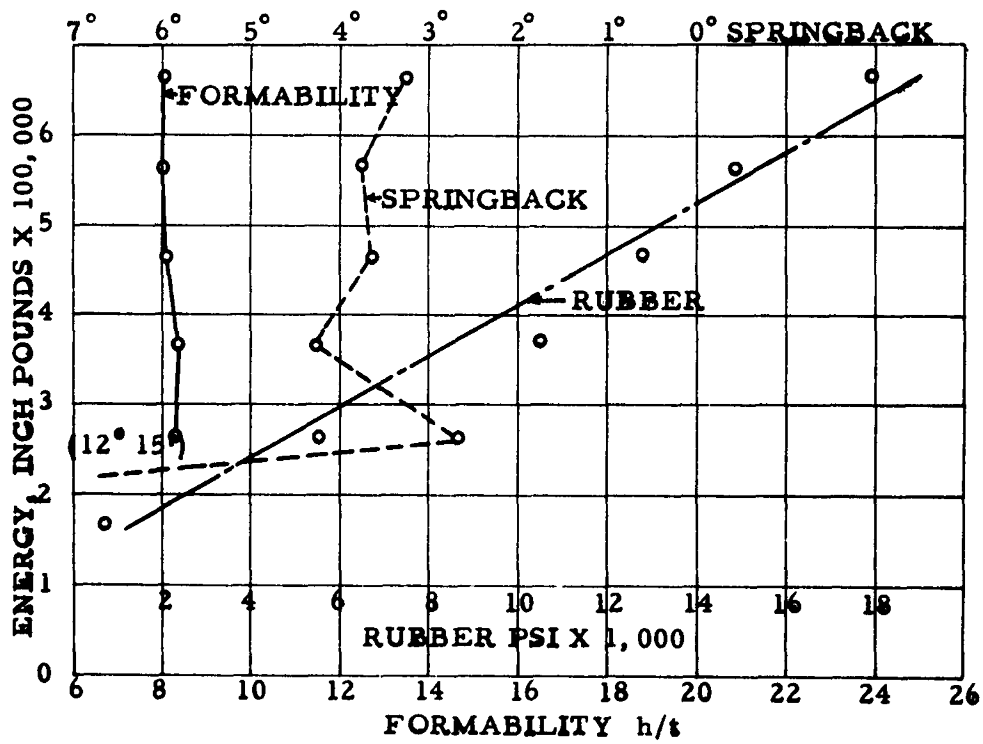


.0275" STAINLESS STEEL SHRINK FLANGES, 4" RADIUS

GRAPH NO. 21

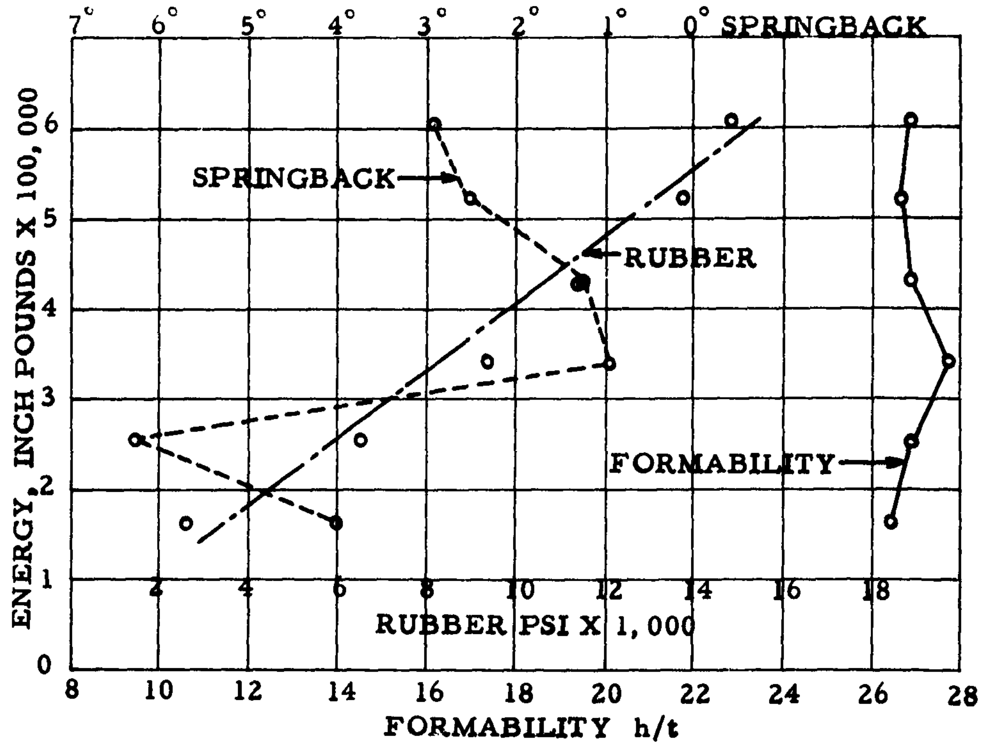


.062" STAINLESS STEEL SHRINK FLANGES, 3" RADIUS

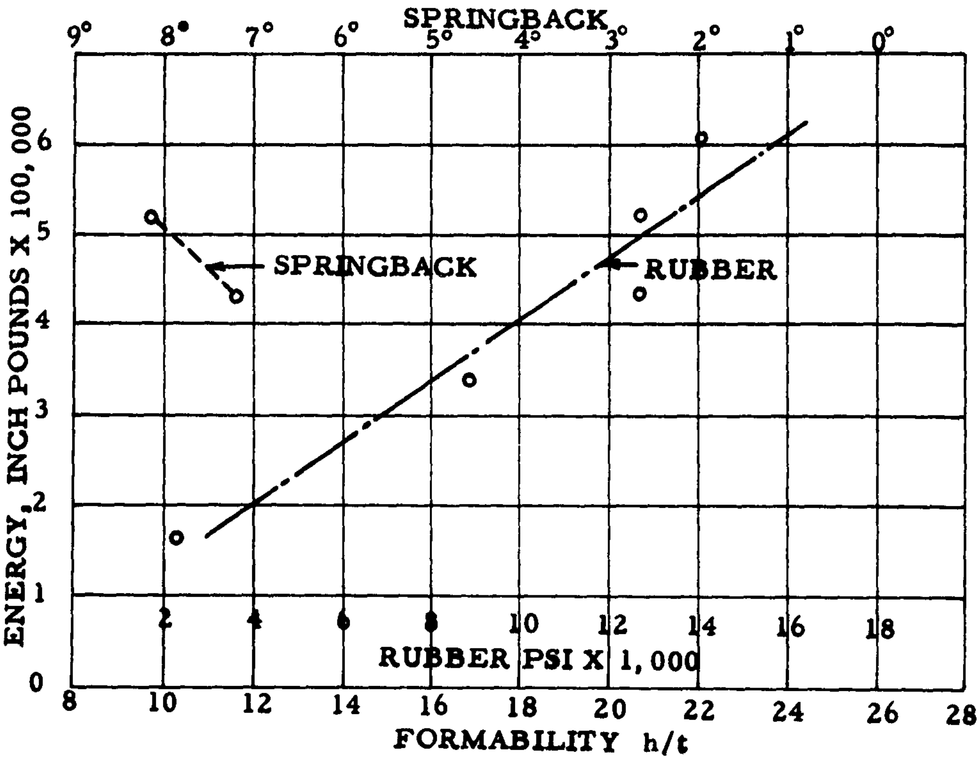


.062" STAINLESS STEEL SHRINK FLANGES, 4" RADIUS

GRAPH No. 22



.0275" STAINLESS STEEL STRETCH FLANGES



.062" STAINLESS STEEL STRETCH FLANGES

GRAPH No. 23

The differences in formability as expressed on the graphs are minor except for the difference where the cavity was not filled and where the cavity was filled by the rubber pad. This difference was more apparent with the heavier sheet materials. It is felt that the 20,000 psi rubber pad forming pressure in the prototype machine would be required for forming thicker gage materials than those tested.

EFFECT OF VELOCITY VARIATION

Formability differences were very small as the velocity of the ram and tooling at impact varied from 404 to 622 inches per second in the test program.

The effects of velocity variation on formability, as was true with the effects of energy variation, are best shown by the shrink flanges formed from the .060" thick, 2024-0 aluminum alloy test blanks. These test blanks were formed at five velocity levels, at a constant energy, as shown on Table 1.

The h/t and h/R values have been plotted on a logarithmic scale on Graph No. 17 with the formability envelope for 2024-0 aluminum alloy determined in a previous (5) series of formability evaluation. The photograph, Figure 2, shows little difference in appearance between the parts formed at the lowest velocities and those formed at the highest.

The best formability over the 3" radius was obtained at the lowest velocity, 404 inches per second, and the next best formability over the same radius at the highest velocity, 622 inches per second.

The best formability over the 4" radius was obtained at 430 inches per second and the next best formability was achieved at the lowest velocity of 404 inches per second.

Graphs 24 through 29 have the velocity, rubber pressure (at constant energy), springback and formability measurement h/t plotted for the shrink and stretch flanges formed in the program.

The results of the formability tests in which the velocity was varied independently of the energy indicated only slight differences in formability.

TOOLING RESPONSE - STATIC

To make an analysis of the response characteristics of the two types of tooling, i.e., stretch and shrink, a static test program was carried out as follows:

SHRINK FLANGE TOOLING

The test machine, and test tooling, as described, with the Form Block 4037 in position, and a new Rubber Pad 4036 of Mosites Compound No. 651-70 of durometer hardness 85, were used in this test.

ACH-37 404 IN./SEC.

ACH-36 430 IN./SEC.

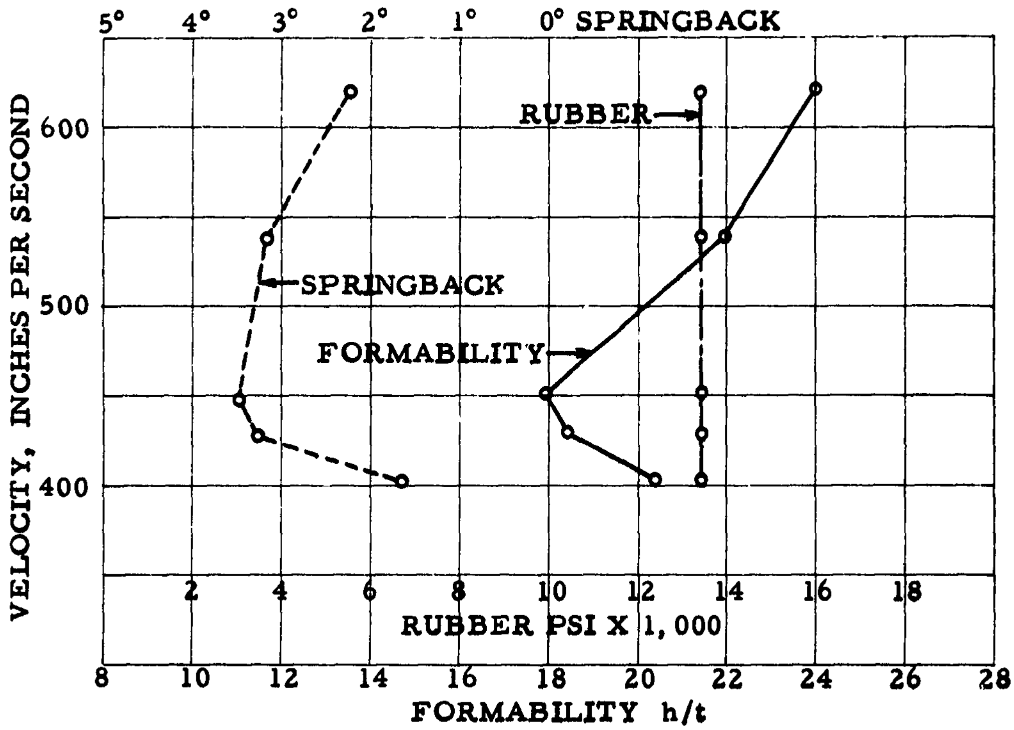
ACH-31 452 IN./SEC.

ACH-34 540 IN./SEC.

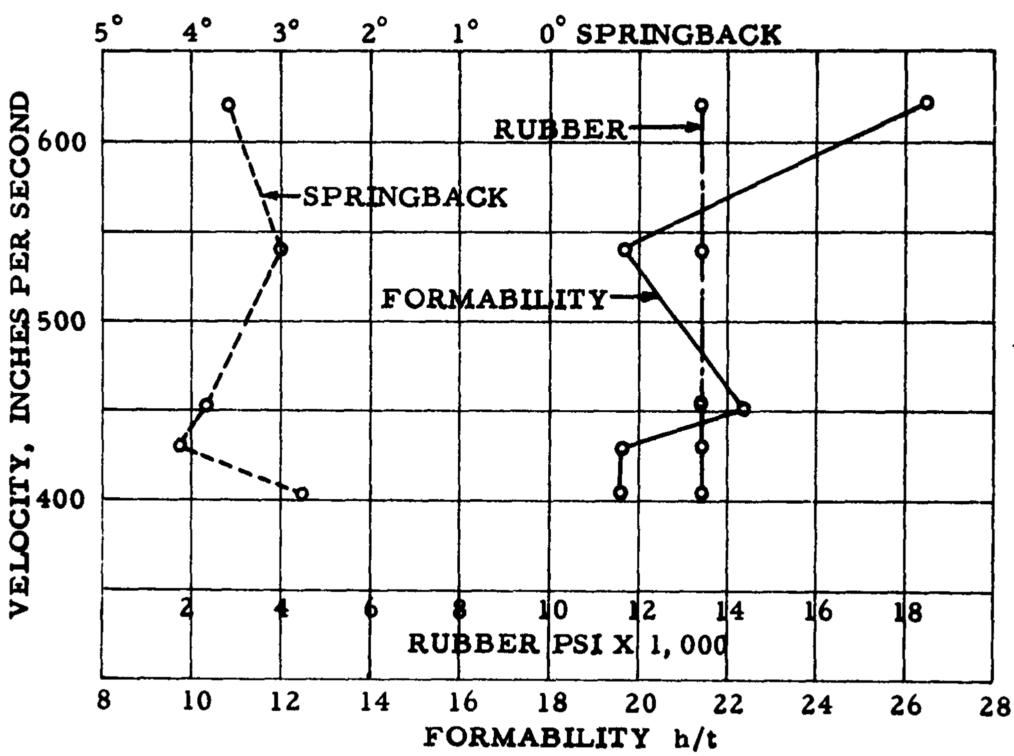
ACH-35 622 IN./SEC.

EFFECT OF VELOCITY CHANGES

FIGURE 2

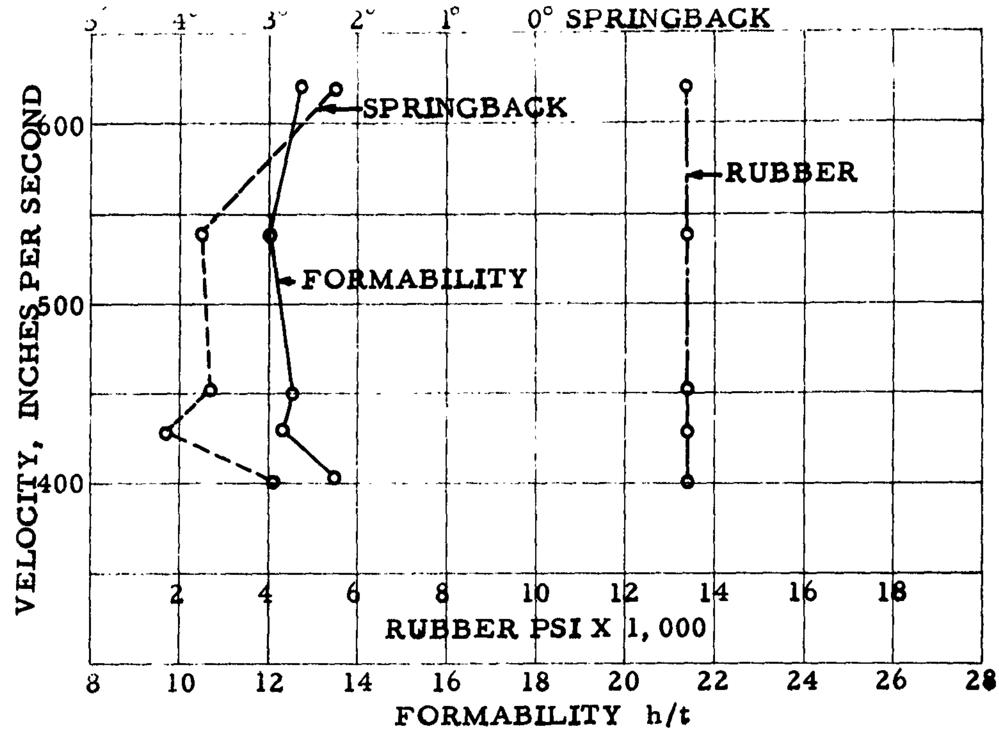


.032" ALUMINUM SHRINK FLANGES, 3" RADIUS

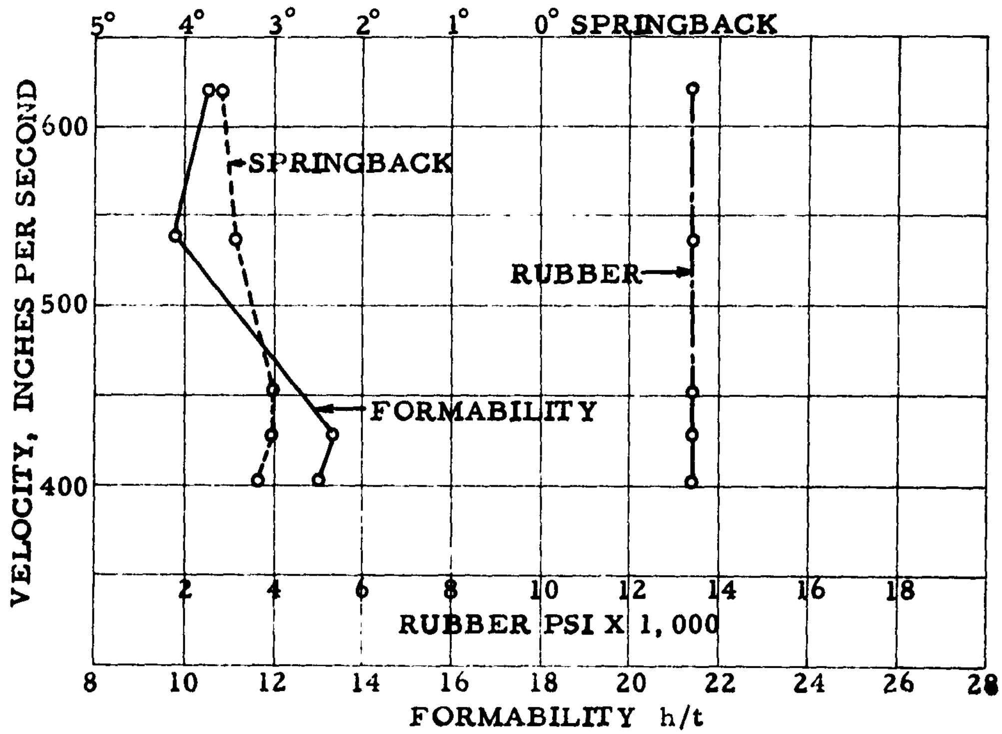


.032" ALUMINUM SHRINK FLANGES, 4" RADIUS

GRAPH No. 24

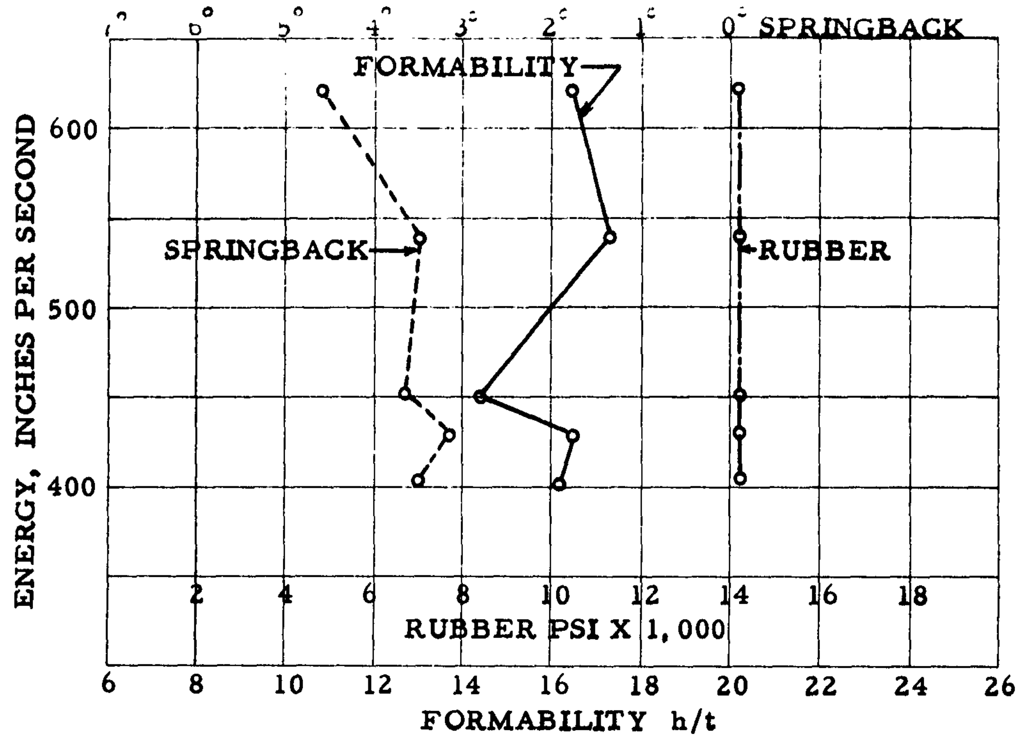


.060" ALUMINUM SHRINK FLANGE, 3" RADIUS

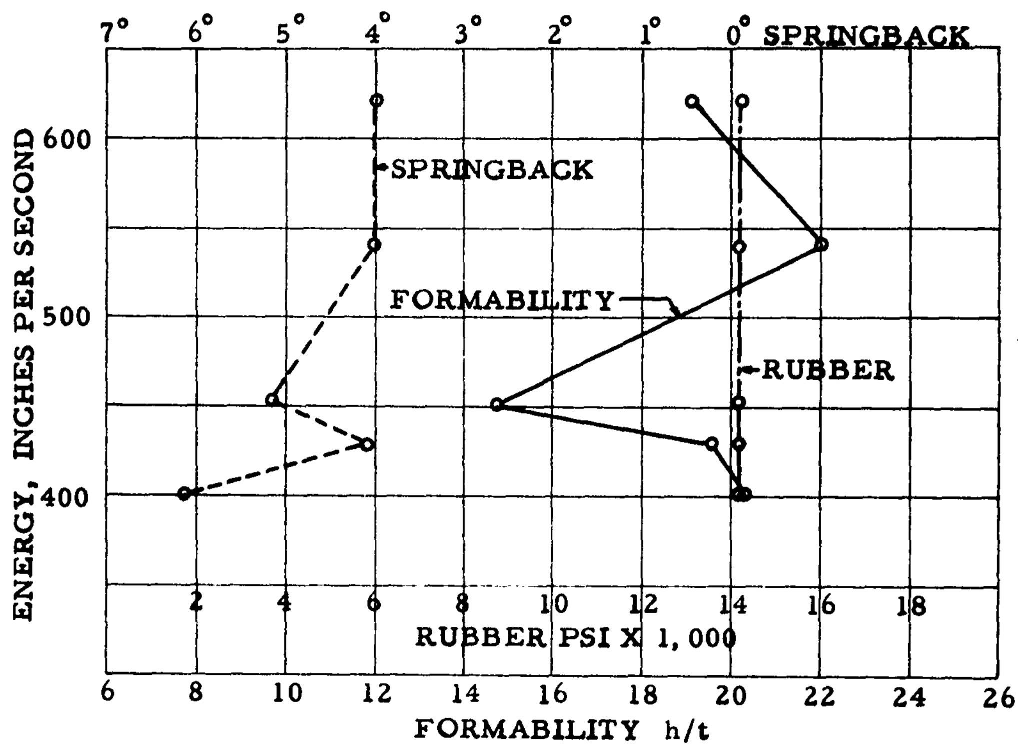


.060" ALUMINUM SHRINK FLANGES, 4" RADIUS

GRAPH No. 2

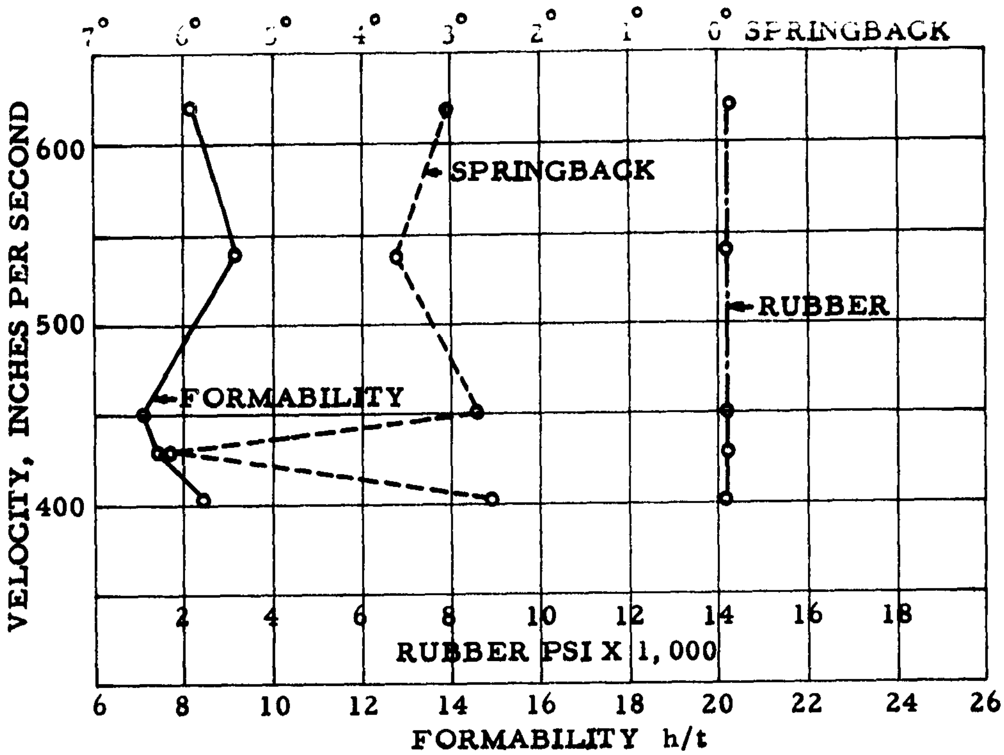


.0275" STAINLESS STEEL SHRINK FLANGES, 3" RADIUS

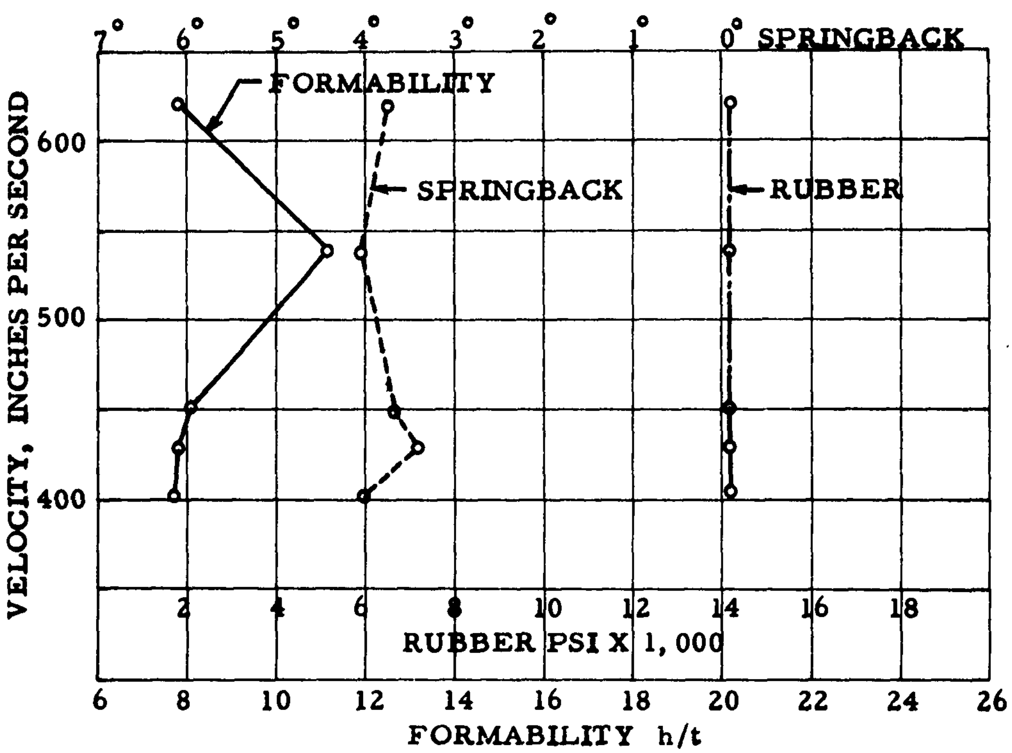


.0275" STAINLESS STEEL SHRINK FLANGES, 4" RADIUS

GRAPH No. 26

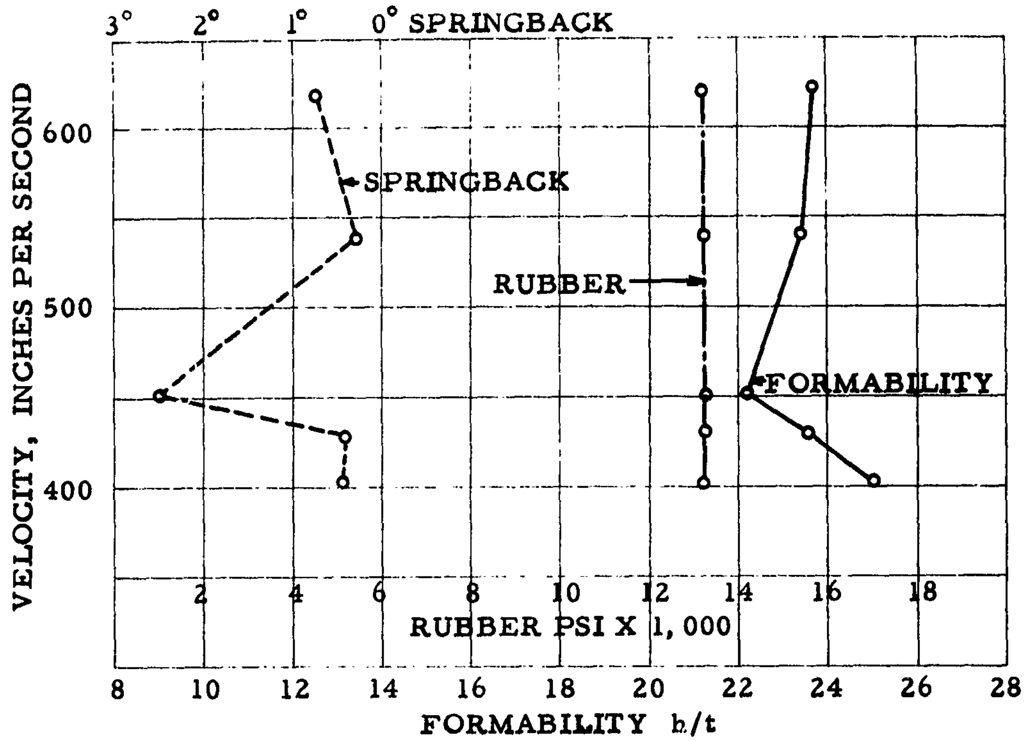


.062" STAINLESS STEEL SHRINK FLANGES, 3" RADIUS

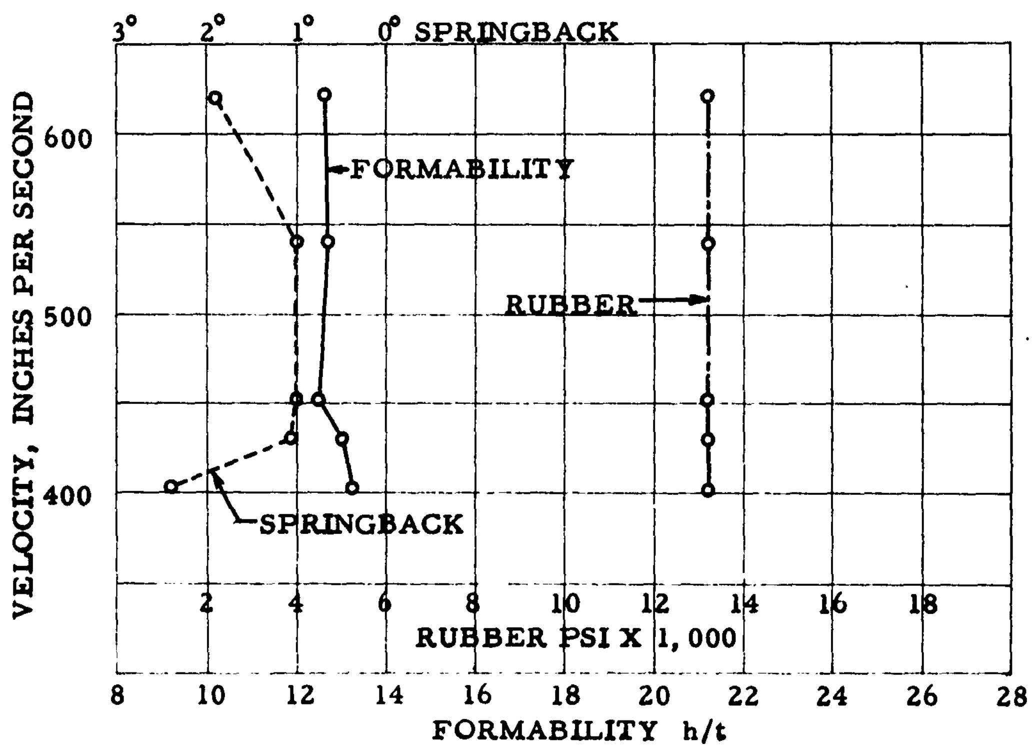


.062" STAINLESS STEEL SHRINK FLANGES, 4" RADIUS

GRAPH No. 27

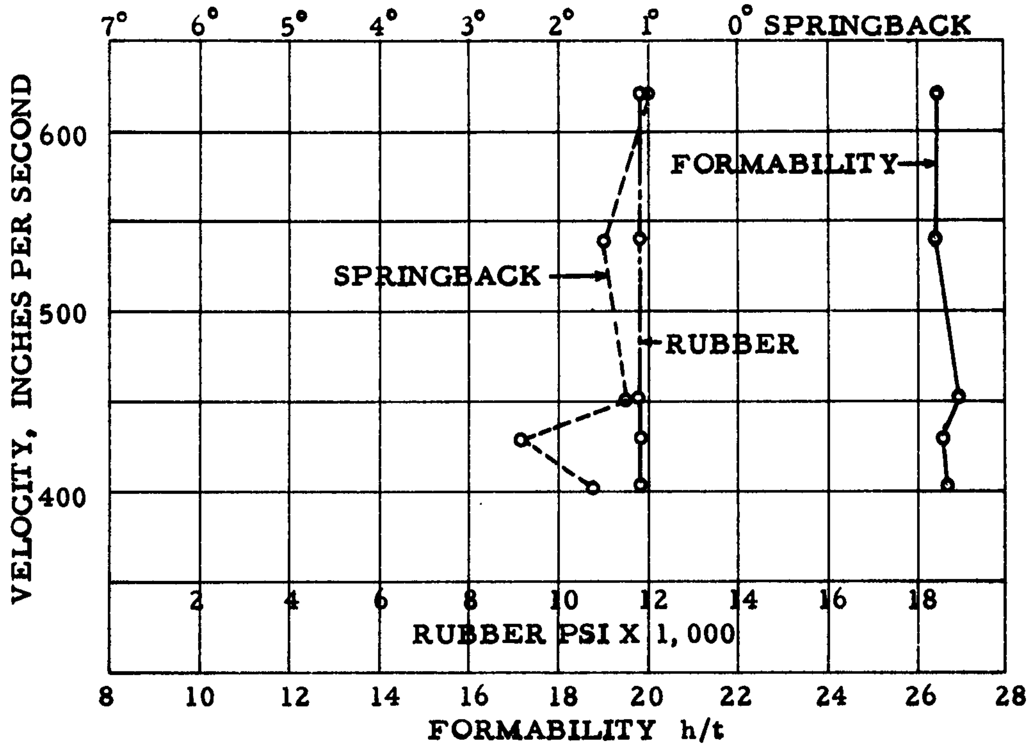


.032" ALUMINUM STRETCH FLANGES

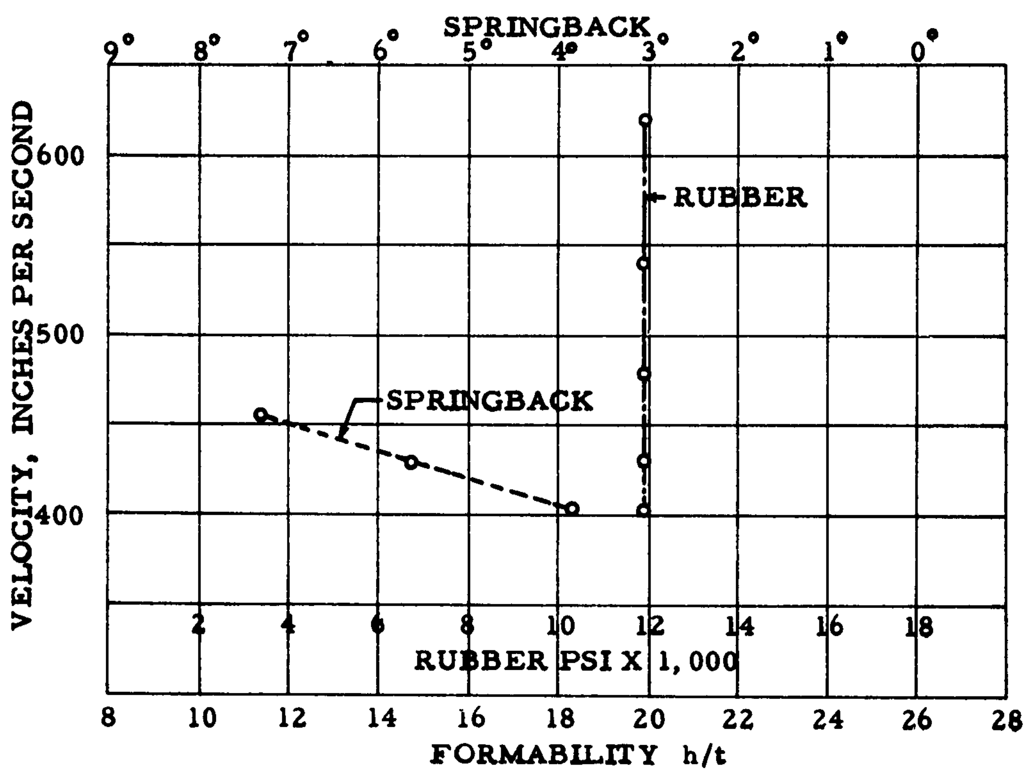


.060" ALUMINUM STRETCH FLANGES

GRAPH No. 28



.0275" STAINLESS STEEL STRETCH FLANGES



.062" STAINLESS STEEL STRETCH FLANGES

GRAPH No. 29

The ram of the test machine was positioned so that contact was made between the face of the rubber pad and the form block. At this position, a dial indicator was positioned with its base located on the Container 4031 and its stylus impinging on the Adaptor 4035.

With the dial indicator set at zero, gas was admitted to the fire chamber of the test machine and the pressure was raised in increments of 100 psig. At each increment, the deflection or penetration of the form block into the rubber pad was read directly off the dial indicator. Sufficient time was allowed after each pressure level was reached to permit equilibrium to be attained within the rubber.

Graph No. 1 shows the results of this test. It will be seen that for a pressure range from zero to 2000 psig, a total penetration of 0.895 inches was obtained.

By calculation, it can be found that to completely fill all voids in the tooling, a penetration of 1.182 inches is required. The actual test penetration of 0.895 inches means that at a maximum static pressure, voids existed in the die cavity.

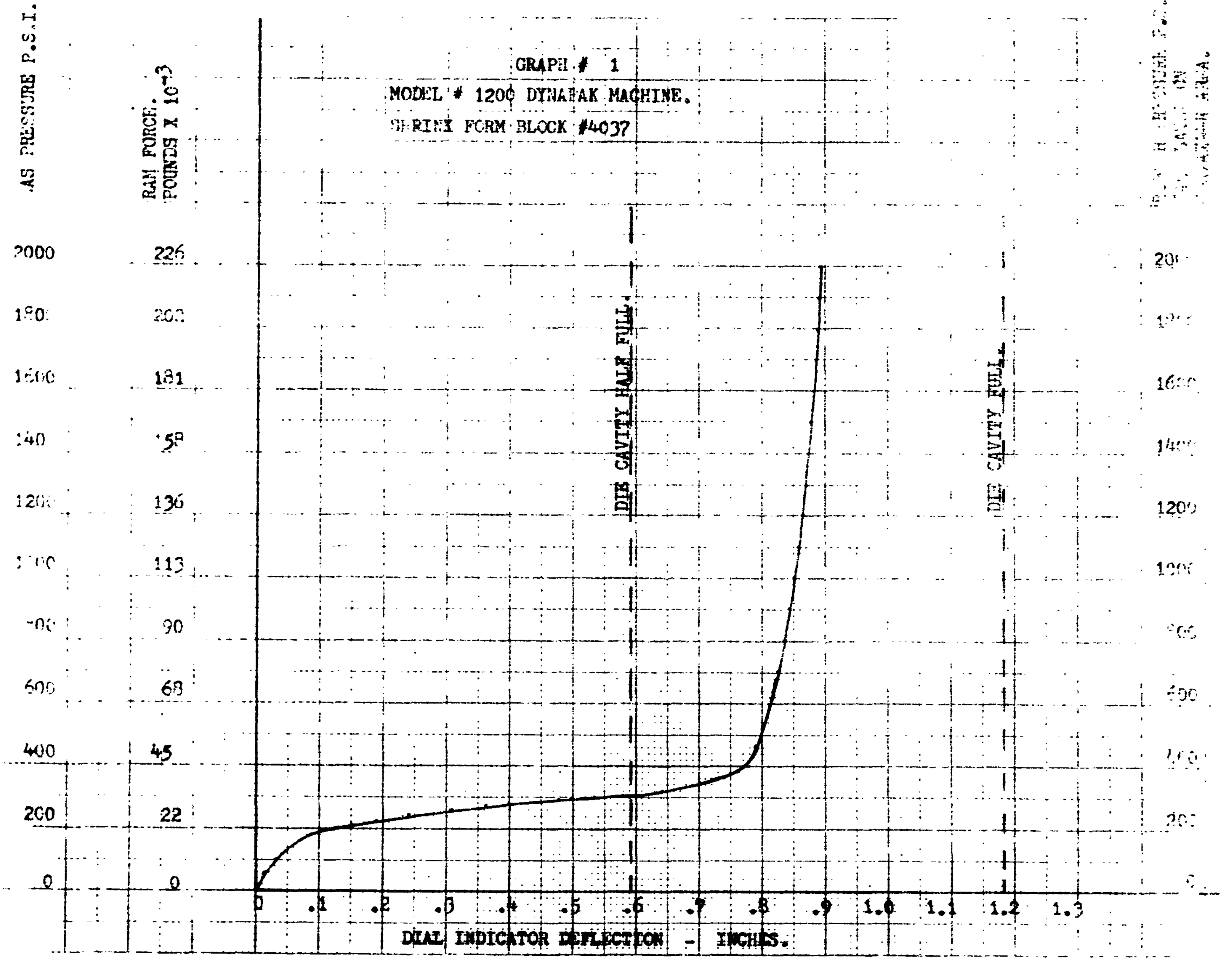
The graph shows that for this particular tooling configuration, 400 psig, equivalent to a load of 45,200 pounds, gave a deflection of approximately 0.75 inch, while the remaining 1600 psig, equivalent to a load of 180,800 pounds, was needed to give a further deflection of approximately 0.125 inch. The rubber area in contact at the start of test represents only 21% of total pad area, this is why initial deflection is high. It would appear that a condition had been reached where reduced "fill" could be expected and that any increase in gas pressure would result in increased rubber pressure with less apparent deflection of the dial indicator. A typical pressure curve will disclose a penetration phase requiring low rubber pressure coupled with a sharp rising pressure spike as rubber flow becomes limited.

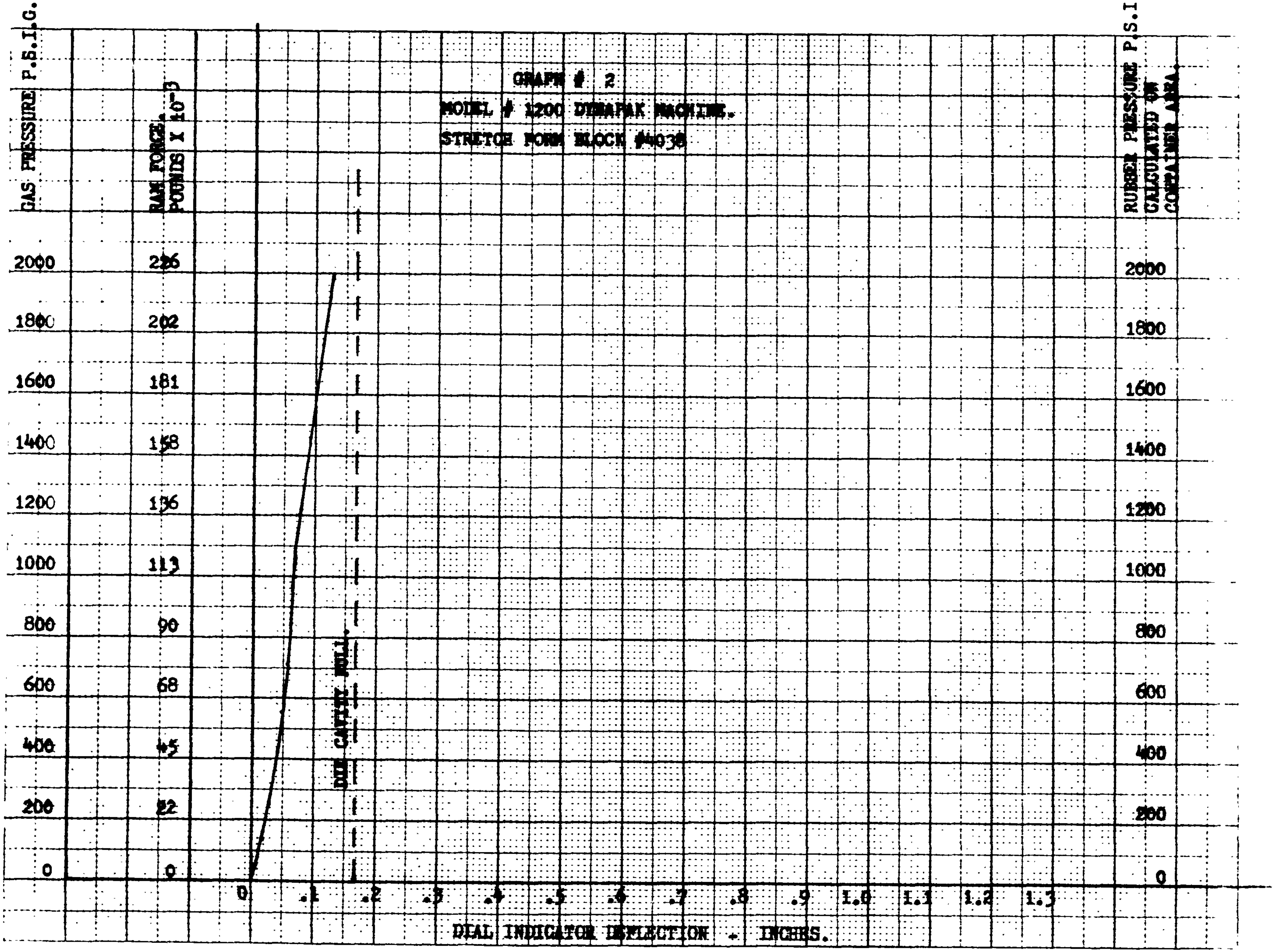
STRETCH FLANGE TOOLING

The static test on this tooling was identical to that described on the shrink flange tooling with the exception that the Form Block 4037 was replaced by Form Block 4038.

Graph No. 2 shows the results of this test. It will be seen that for a pressure range from zero to 2000 psig, a total penetration of 0.131 inches was obtained.

Again, by calculation, it can be found that to completely fill all voids in the tooling, a penetration of 0.167 inches is required. The actual test penetration of 0.131 inches means that voids existed in the die cavity, as in the previous test. The graphs shows that for this particular tooling configuration that the deflection is approximately directly proportional to the applied load. The "stiffness" compared with that of the shrink flange tooling is due to the cavity area/container area ratio results in 89% of the rubber


GRAPH # 1
MODEL # 1200 DYNAPAK MACHINE.
FORM BLOCK #4037
AS PRESSURE P.S.I.
RAM FORCE.
POUNDS X 10-3
2000
400
200
0
226
181
136
113
90
68
45
22
0
DIE CAVITY HALF FULL.
DIE CAVITY FULL.
1200
DIAL INDICATOR DEFLECTION - INCHES.
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3


GRAPH # 2
MODEL # 1200 DYNAPAK MACHINE.
STRETCH FORM BLOCK #4038
GAS PRESSURE P.S.I.G.
RAM FORCE, POUNDS X 10^{-3}
RUBBER PRESSURE P.S.I. CALCULATED ON CONTAINER AREA.
DIE CAVITY FULL.
DIAL INDICATOR DEFLECTION - INCHES.
2000
1800
1600
1400
1200
1000
800
600
400
200
0
226
202
181
158
136
113
90
68
45
22
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3

pad area being in contact with the form block, and consequently, most of the rubber is in direct compression.

TOOLING RESPONSE - DYNAMIC

The five graphs, Nos. 3 through 7, are typical of the eleven graphs derived from data obtained by use of the high speed movie camera, as described under "Instrumentation".

The time/displacement curves were used to produce by graphical methods the velocity curve, acceleration curve and load/displacement curve.

It is of interest to note that Graph Nos. 5 and 6 are of tests made where the energy levels and ram masses were equal. These tests were not consecutive, as many other tests requiring control adjustments and die changes came between them, nevertheless, the impact velocities are identical, substantiating the fact that precise, repetitive control over the velocity and energy are easily achieved with the type of actuator used on the test machines.

Typical acceleration curves and load/displacement curves for both shrink and stretch forming are shown on Graph Nos. 8 through 12 and it will be readily seen that these curves are consistent with the respective curves obtained in the static tests. No important difference in static and dynamic pressure response are evident, except that higher rubber pressures are achievable under the dynamic conditions because of the greater energy release.

Also shown on these graphs are the "G" loadings encountered. From these loadings, force and rubber pressure are derived and included.

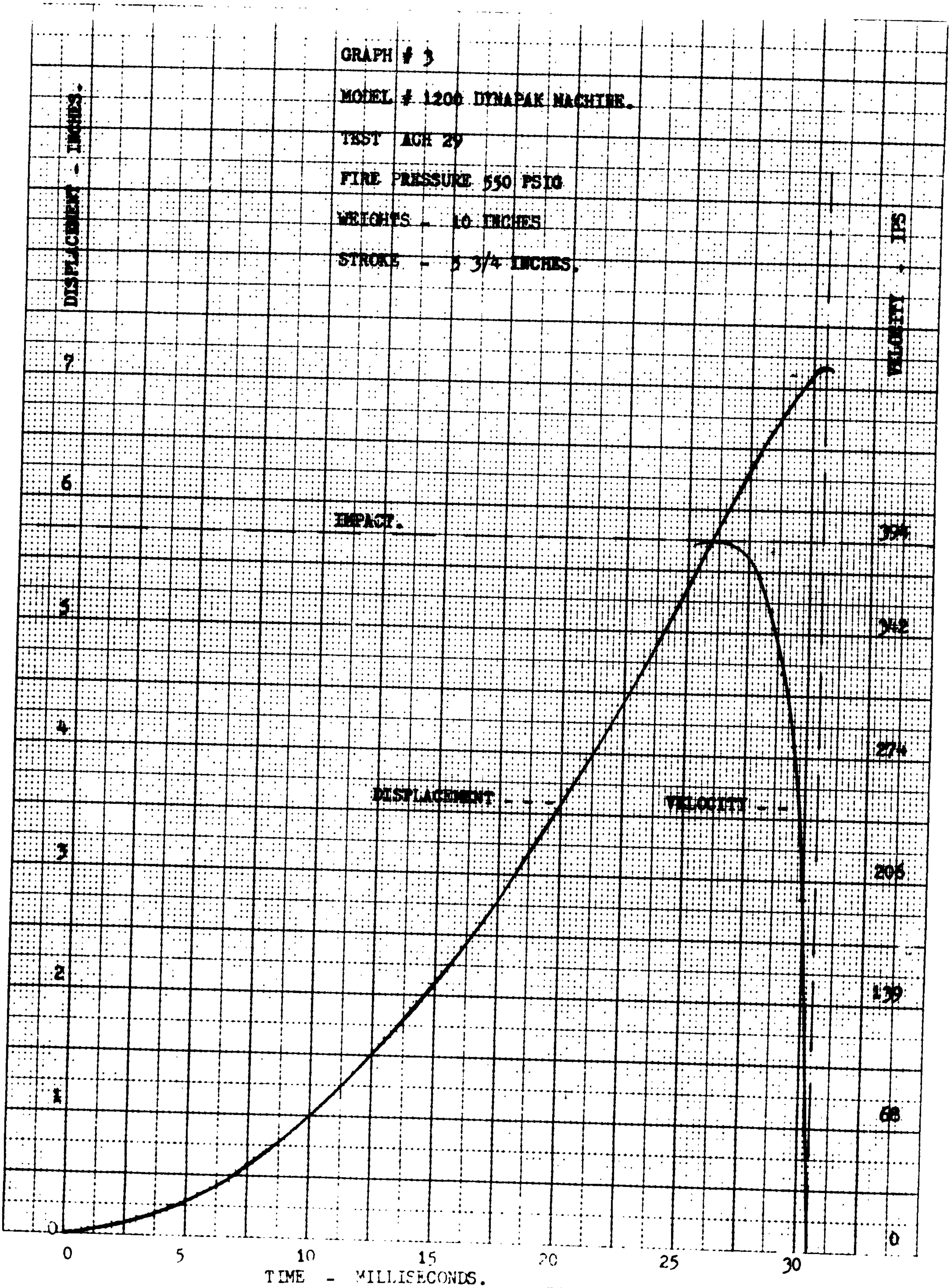
By integration of the load/displacement envelope, the total absorbed energy was obtained. It will be seen that in some cases, the measured energy is numerically larger than the theoretical energy, this discrepancy is a measure of the construction accuracy of the series of curves.

MACHINE DYNAMICS ANALYSIS

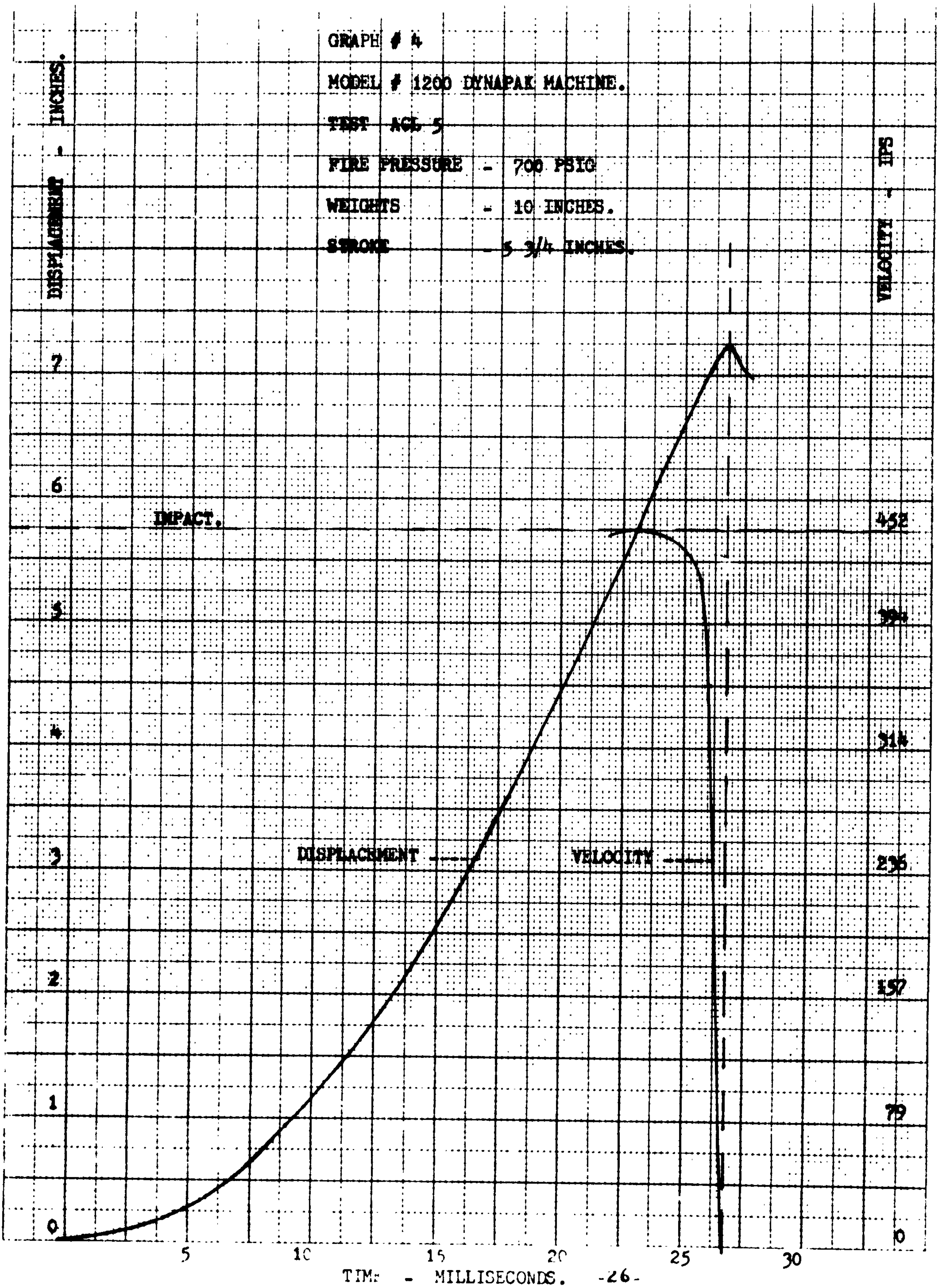
The fundamental principles of the existing high energy machines will be followed in the design of the prototype machine.

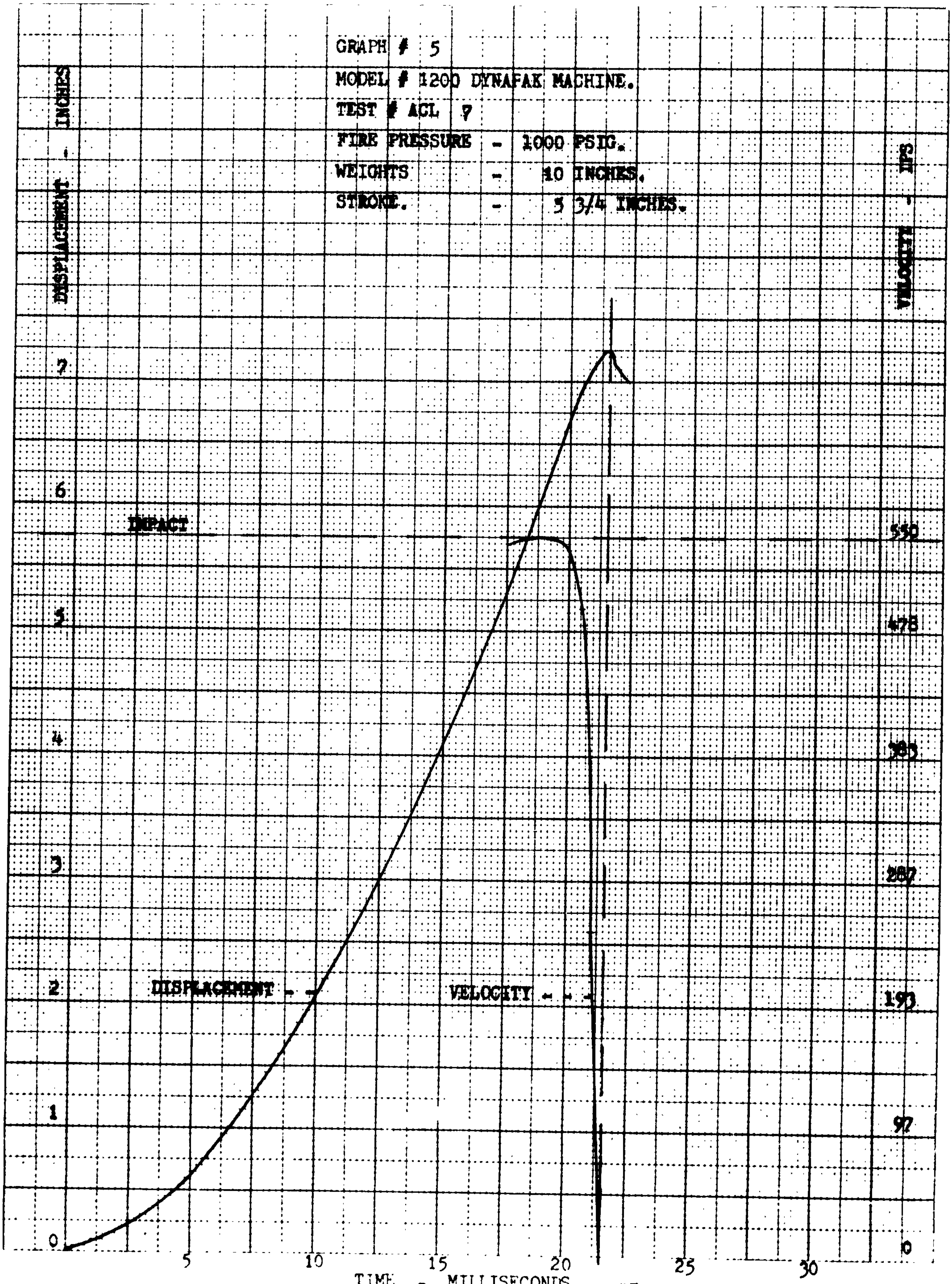
Figure No. 12 is a diagrammatic drawing of the self-reacting construction of the prototype machine, and the relative motion of its main components, the ram and the bolster can be conveniently solved by use of the impulse-momentum relationship.

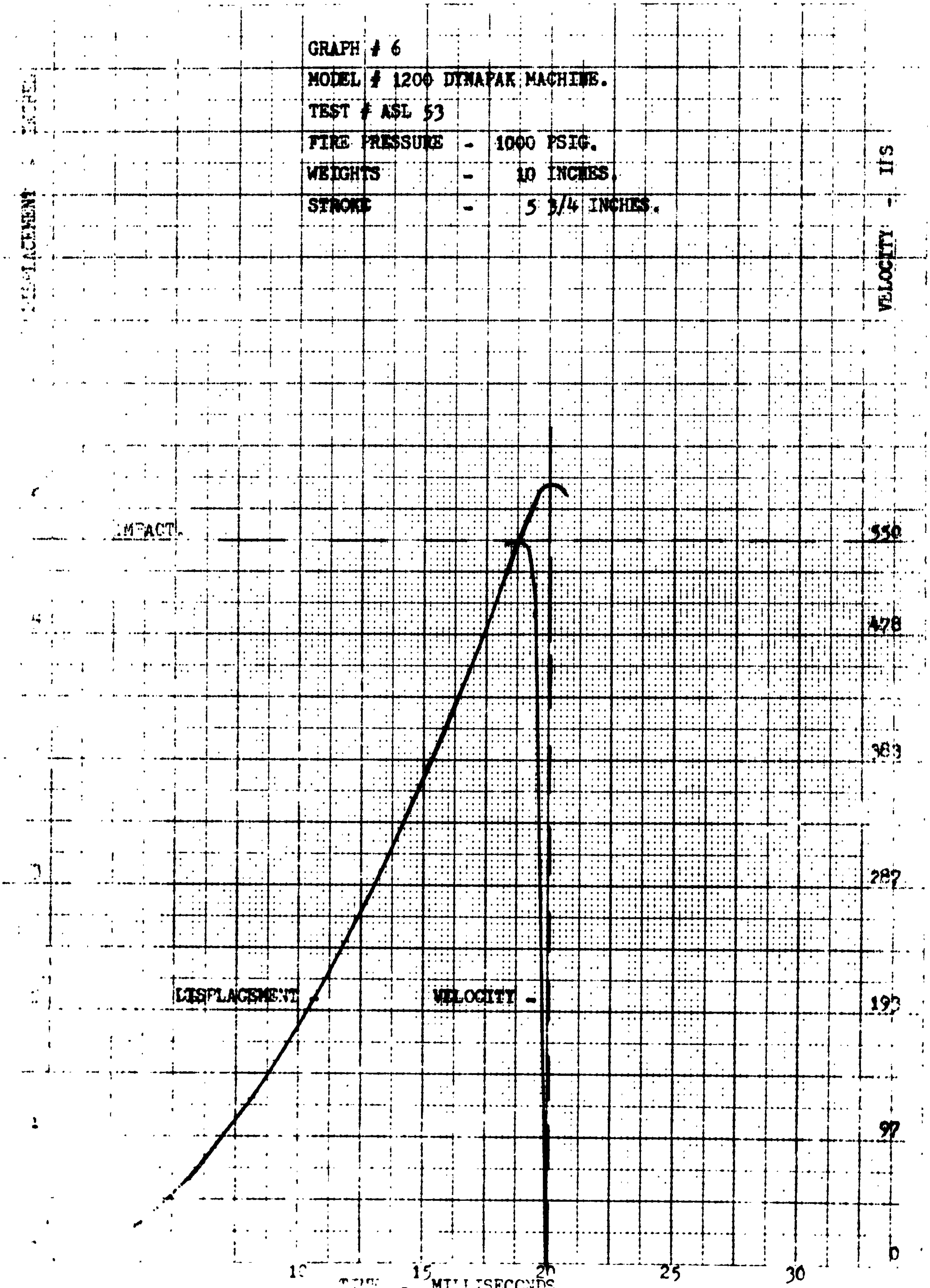
Consider the machine as a free body, and neglect normal gravitational influences.



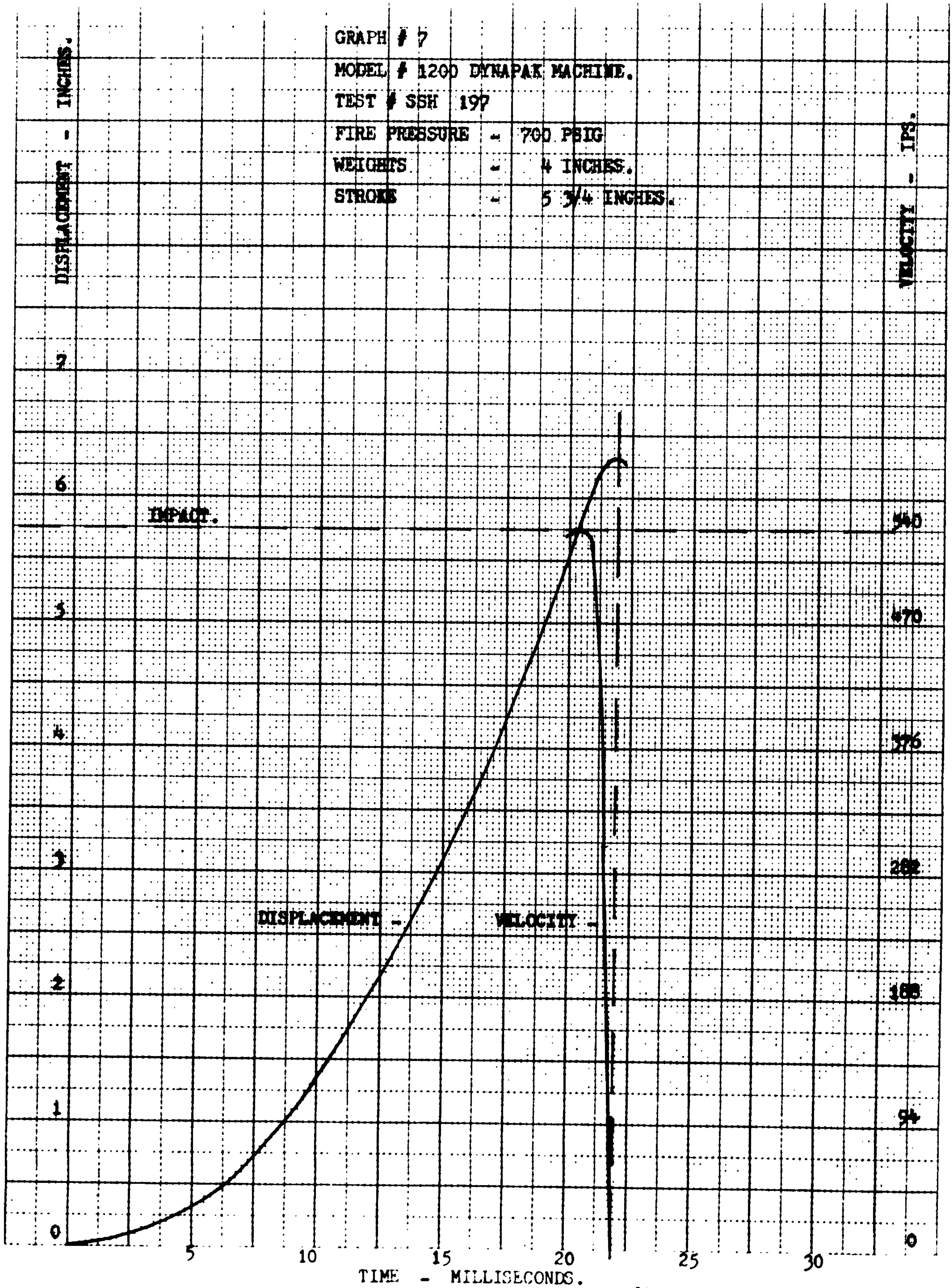
GRAPH # 3
MODEL # 1200 DYNAPAK MACHINE.
TEST ACH 29
FIRE PRESSURE 550 PSIG
WEIGHTS - 10 INCHES
STROKE - 5 3/4 INCHES.
DISPLACEMENT - INCHES.
VELOCITY - IPS
IMPACT.
DISPLACEMENT - - -
VELOCITY - -
0
1
2
3
4
5
6
7
0
68
139
206
274
342
394
0
5
10
15
20
25
30
TIME - MILLISECONDS.


GRAPH # 4
MODEL # 1200 DYNAPAK MACHINE.
TEST AGL 5
FIRE PRESSURE - 700 PSIG
WEIGHTS - 10 INCHES.
STROKE - 5 3/4 INCHES.
DISPLACEMENT - INCHES.
VELOCITY - IPS
IMPACT.
DISPLACMENT
VELOCITY
0
1
2
3
4
5
6
7
0
79
157
236
314
394
452
5
10
15
20
25
30
TIME - MILLISECONDS.

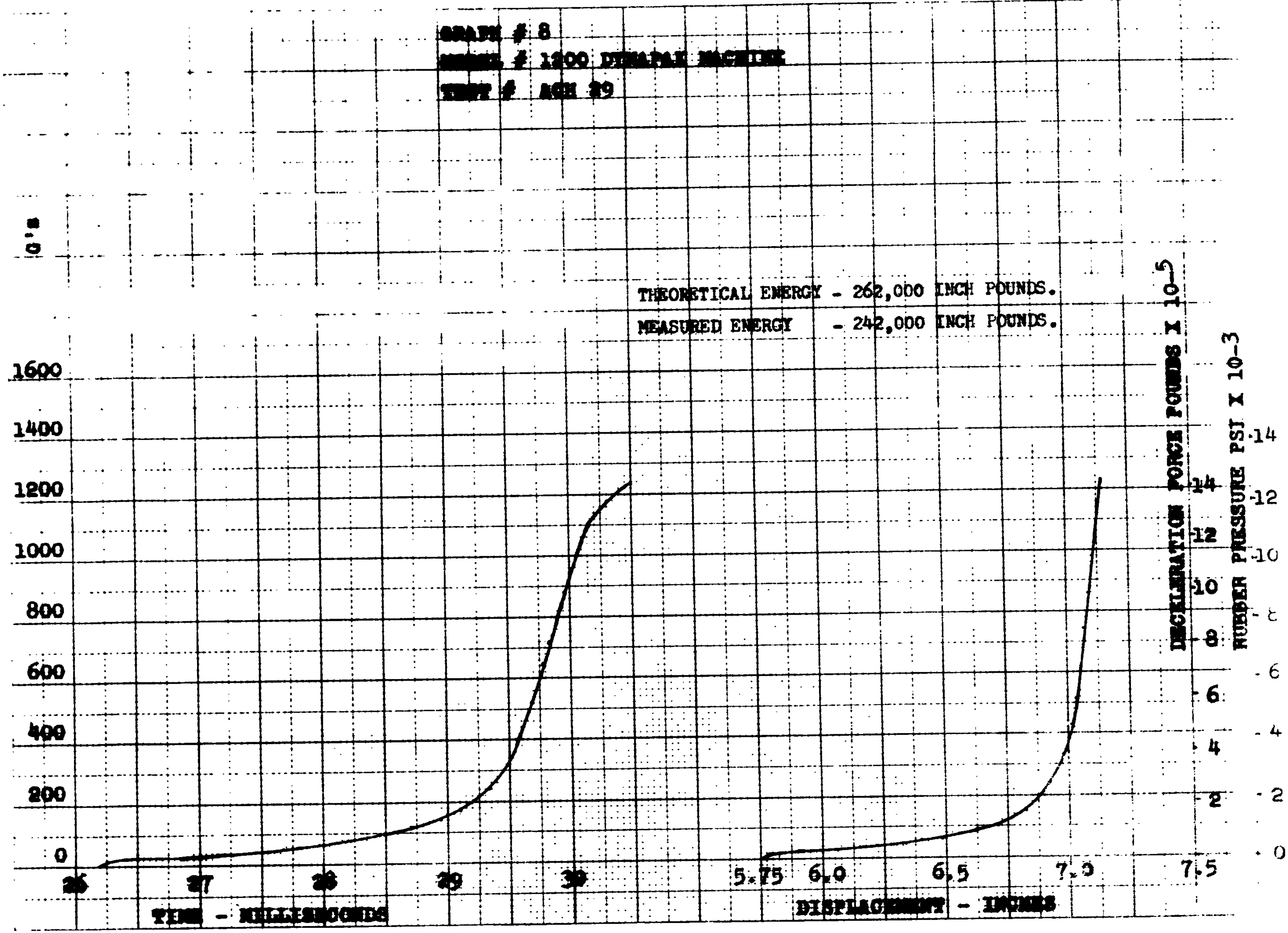

GRAPH # 5
MODEL # 1200 DYNAFAK MACHINE.
TEST # ACL 7
FIRE PRESSURE - 1000 PSIG.
WEIGHTS - 10 INCHES.
STROKE. - 5 3/4 INCHES.
DISPLACEMENT - INCHES
VELOCITY - IPS
IMPACT
DISPLACEMENT
VELOCITY
0
1
2
3
4
5
6
7
0
97
193
287
383
478
550
5
10
15
20
25
30
TIME - MILLISECONDS.



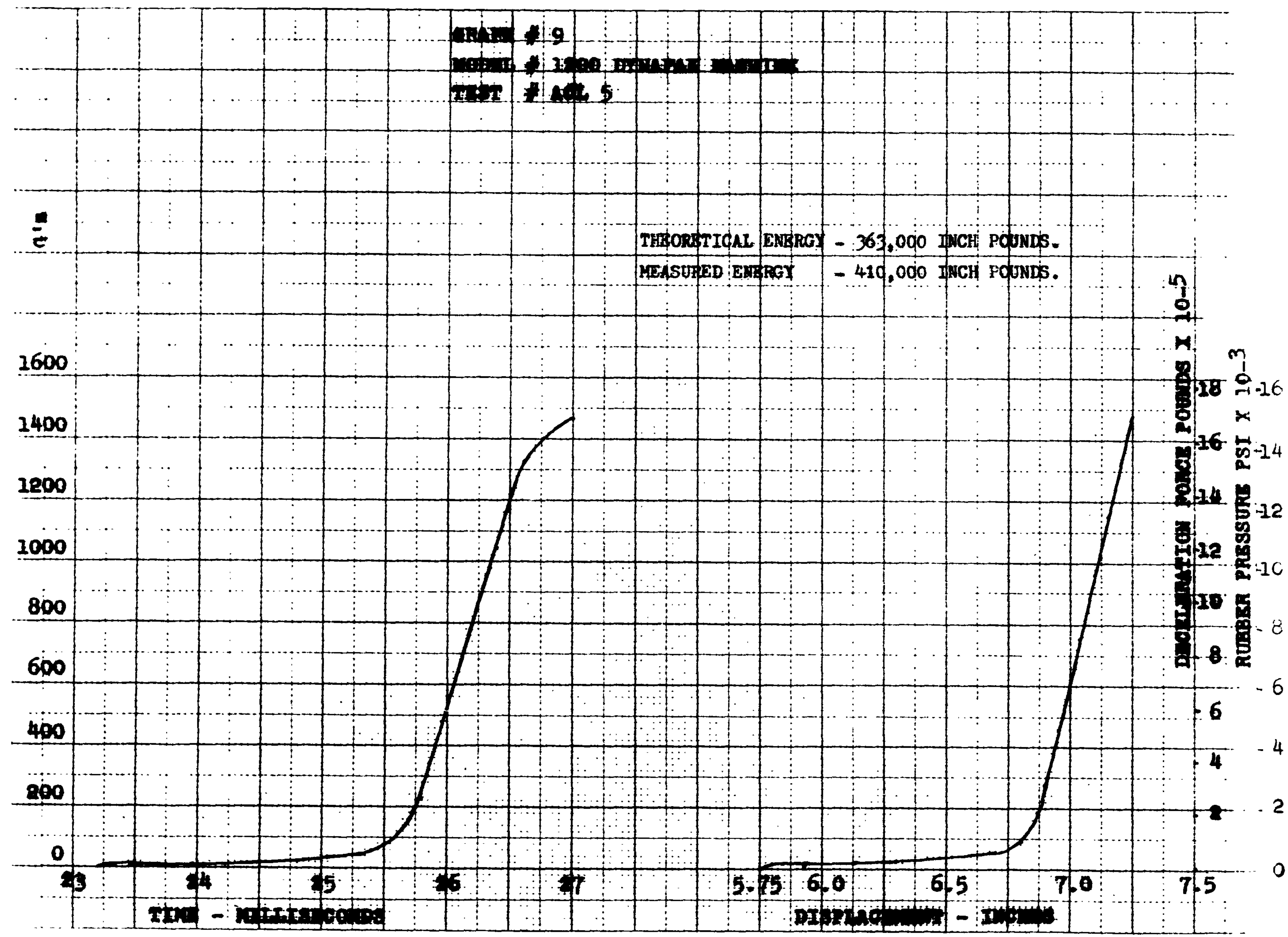
GRAPH # 6
MODEL # 1200 DYNAPAK MACHINE.
TEST # ASL 53
FIRE PRESSURE - 1000 PSIG.
WEIGHTS - 10 INCHES.
STROKE - 5 3/4 INCHES.
DISPLACEMENT - INCHES
VELOCITY - IPS
IMPACT
DISPLACEMENT
VELOCITY
550
478
383
287
193
97
0
10
15
20
25
30
TIME - MILLISECONDS.



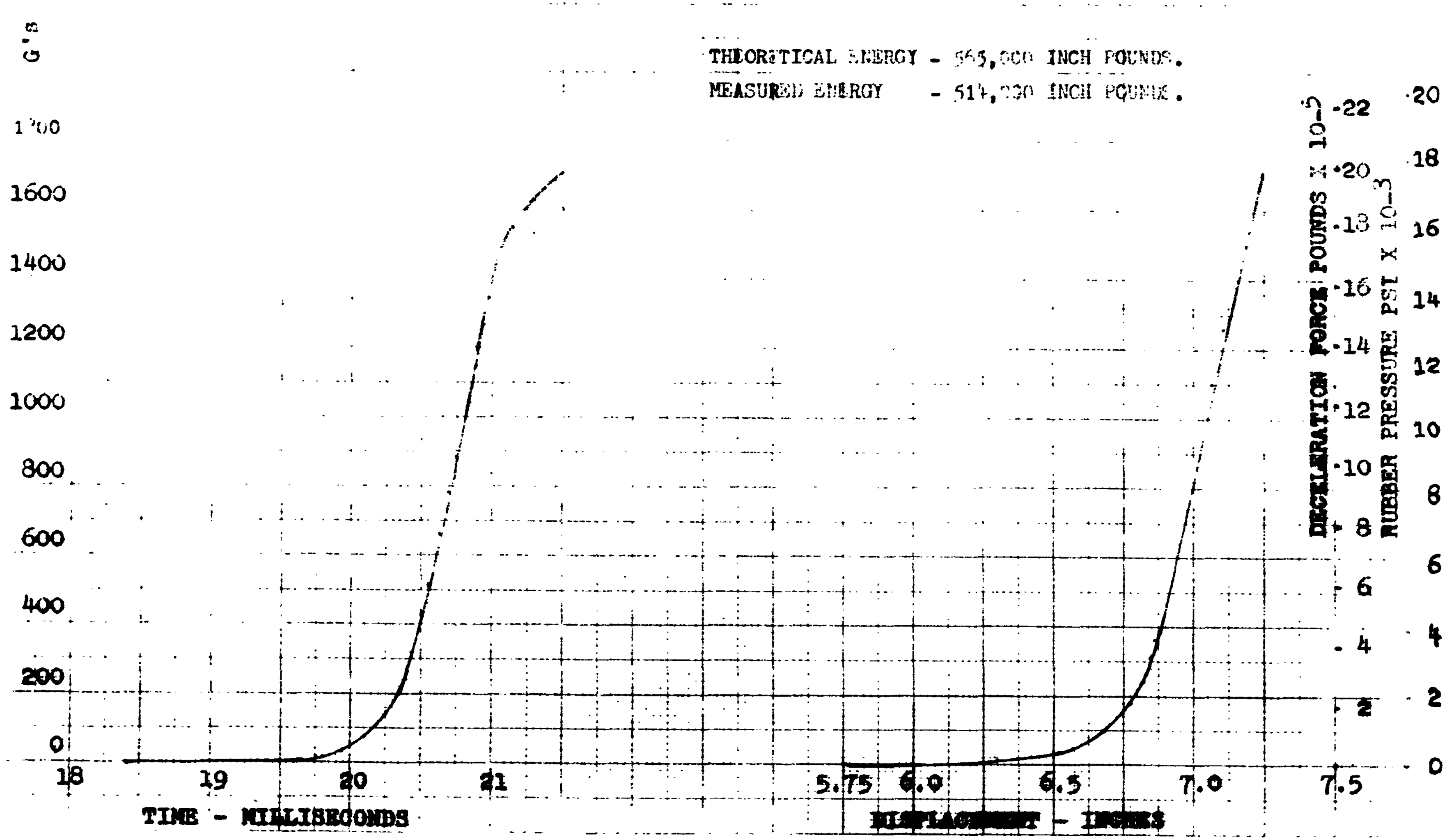
GRAPH # 7
MODEL # 1200 DYNAPAK MACHINE.
TEST # SSH 197
FIRE PRESSURE - 700 PSIG
WEIGHTS - 4 INCHES.
STROKE - 5 3/4 INCHES.
DISPLACEMENT - INCHES.
VELOCITY - IPS.
IMPACT.
DISPLACEMENT -
VELOCITY -
0
1
2
3
4
5
6
7
94
188
282
376
470
540
0
5
10
15
20
25
30
TIME - MILLISECONDS.

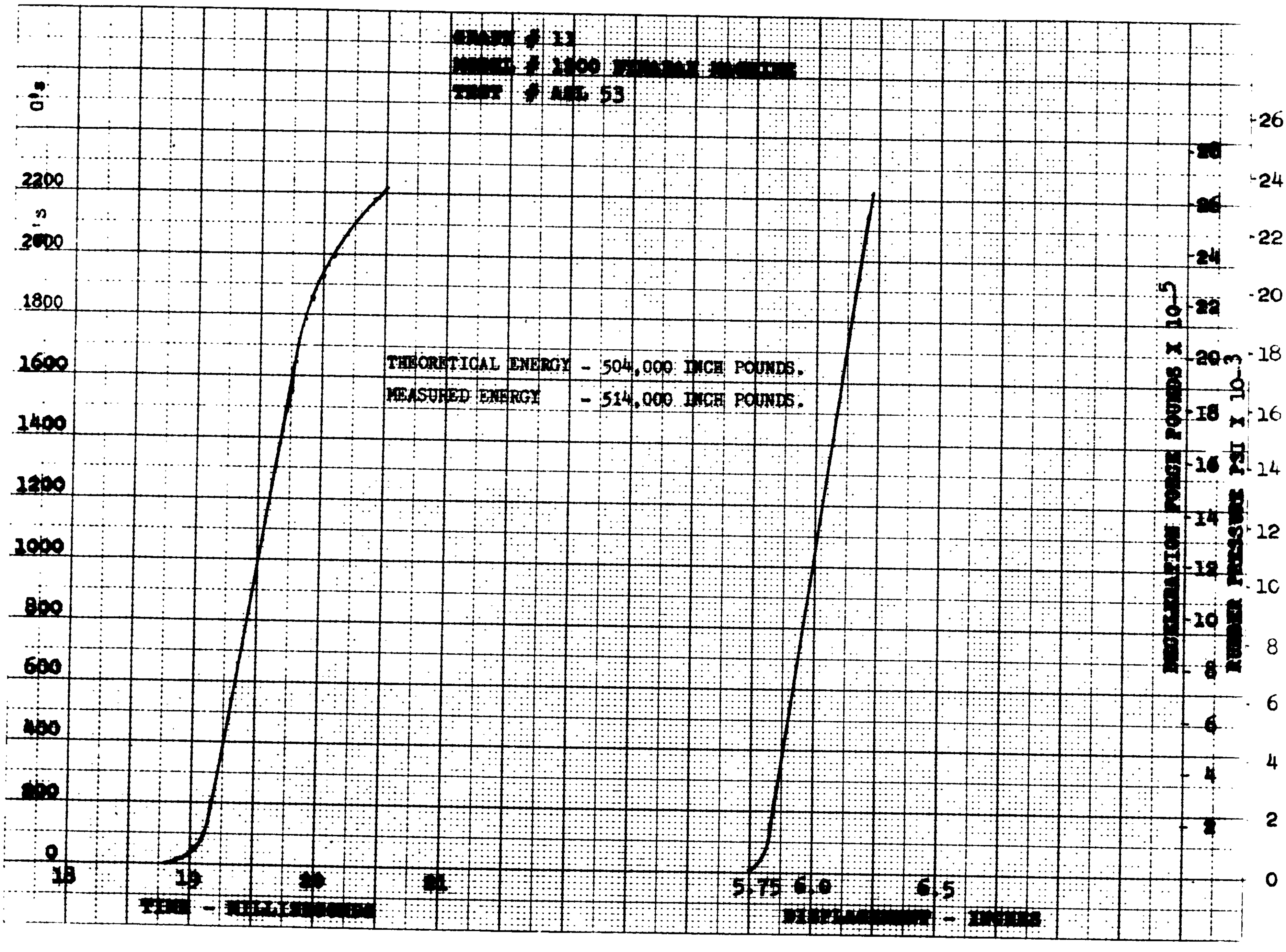


8
1200
AGH 29
G's
THEORETICAL ENERGY - 262,000 INCH POUNDS.
MEASURED ENERGY - 242,000 INCH POUNDS.
1600
1400
1200
1000
800
600
400
200
0
27
29
5.75
6.0
6.5
7.5
DECELERATION FORCE POUNDS X 10-5
RUBBER PRESSURE PSI X 10-3
14
12
10
8
6
4
2
0


GRAPH # 9
MODEL # 1200 DYNAPAK MACHINE
TEST # AGL 5
THEORETICAL ENERGY - 363,000 INCH POUNDS.
MEASURED ENERGY - 410,000 INCH POUNDS.
1600
1400
1200
1000
800
600
400
200
0
23
24
25
26
27
TIME - MILLISECONDS
5.75
6.0
6.5
7.0
7.5
DISPLACEMENT - INCHES
DECELERATION FORCE POUNDS X 10-5
RUBBER PRESSURE PSI X 10-3

GRAPH # 10
MODEL # 1200 DYNAPAK MACHINE
TEST # ACL 7




THEORETICAL ENERGY - 504,000 INCH POUNDS.
MEASURED ENERGY - 514,000 INCH POUNDS.
2200
1800
1600
1400
1200
1000
800
600
400
200
0
5.75 6.0
6.5
26
24
22
20
18
16
14
12
10
8
6
4
2
0

GRAPH # 12
MODEL # 1200 DYNAPAK MACHINE
TEST # S&H 197

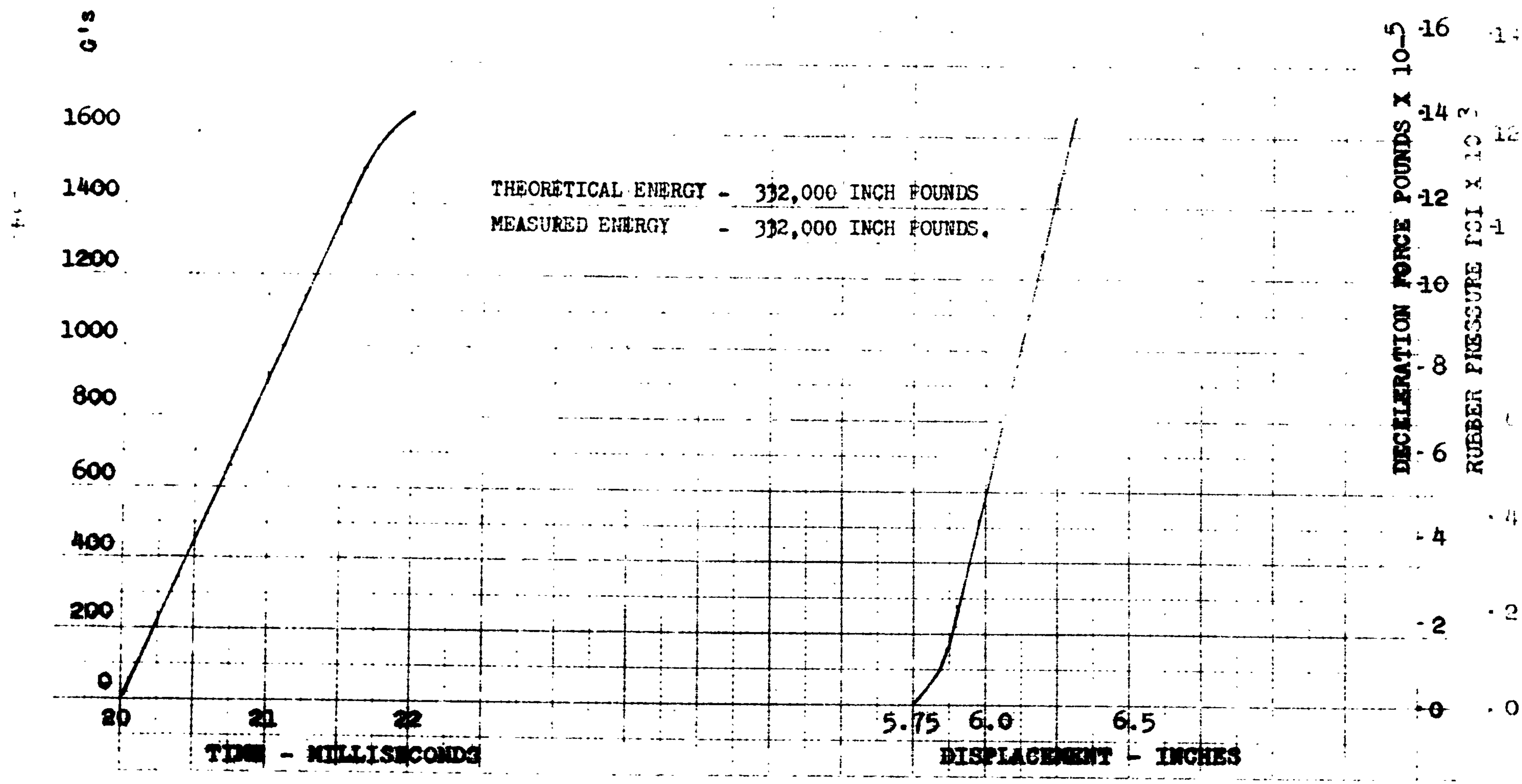
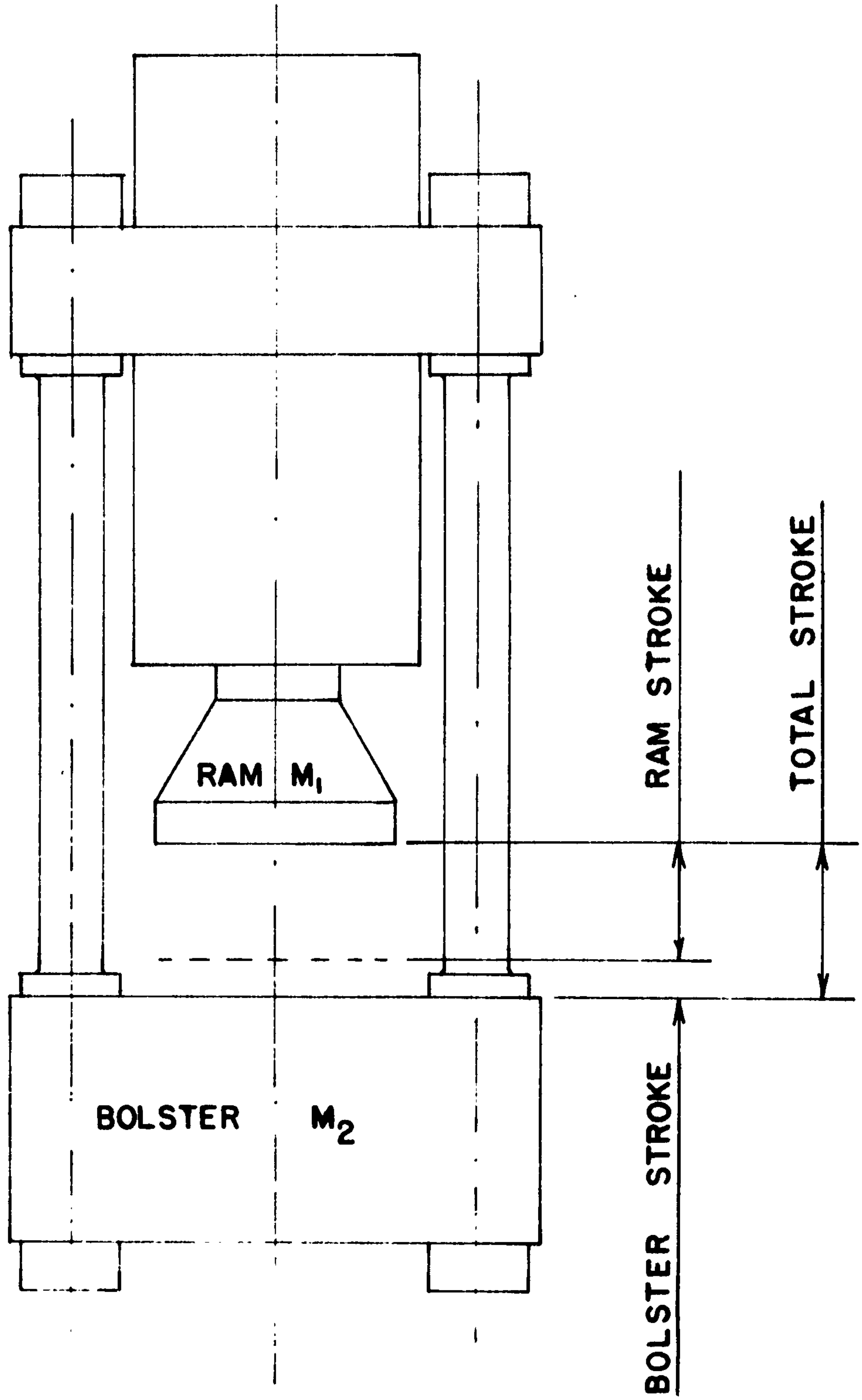


FIGURE NO. 12



From the cocked position, the ram (M_1) is released to strike to bolster (M_2) which is an integral part of the actuator. The driving impulse acts equally on both the ram and the bolster.

$$\int Fdt = M_1V_1 \qquad \int -Fdt = M_2V_2$$

$$M_1V_1 = -M_2V_2 \qquad \text{------------------------(1)}$$

$$FM_1A_1 = -FM_2A_2$$

$$M_1A_1 = -M_2A_2 \qquad \text{------------------------(2)}$$

As an equal impulse acts on both tool surfaces during impact, the above equations describe both the ram acceleration and tool impact portions of the cycle. An obvious conclusion from (1) is that the velocities of both ram and bolster are always opposite in direction.

Relative Energy Distribution:

E_1 = Kinetic Energy of the Ram = $\frac{1}{2}M_1V_1^2$

E_2 = Kinetic Energy of the Actuator = $\frac{1}{2}M_2V_2^2$

E = Total Energy Converted to Kinetic Energy

$E = E_1 + E_2$

$$E_1 = \tfrac{1}{2}M_1V_1^2, \quad E_2 = \tfrac{1}{2}M_2V_2^2$$

$$\text{from (1)} \quad V_2 = \frac{-M_1V_1}{M_2} \qquad V_2^2 = \frac{M_1^2V_1^2}{M_2^2}$$

$$\frac{E_1}{E_2} = \frac{M_1}{M_2} \times \frac{V_1^2}{\frac{M_1^2}{M_2^2} \quad V_1^2}$$

$$\frac{E_1}{E_2} = \frac{M_1M_2^2}{M_2M_1^2} = \frac{M_2}{M_1}$$

$$E_1M_1 = E_2M_2 \qquad \text{------------------------(3)}$$

$$\text{and } E = E_1 + E_2$$

$$E = E_1 + \frac{M_1E_1}{M_2} \qquad \text{------------------------(4)}$$

$$\text{and } V_1^2 = \frac{2E}{M_1\left(1 + \frac{M_1}{M_2}\right)} \qquad \text{------------------------(5)}$$

Relative Velocity of Ram and Bolster:

$$V_R = V_1 - V_2 \qquad V_2 = \frac{-M_1V_1}{M_2}$$

$$V_R = V_1 + \frac{M_1V_1}{M_2} \qquad V_1 = \frac{V_R}{1 + \frac{M_1}{M_2}} \cdot \frac{V_R^2}{(1 + \frac{M_1}{M_2})^2} = \frac{2E}{M_1\ (1 + \frac{M_1}{M_2})} \text{ ---(6)}$$

$$E = \frac{\frac{1}{2}M_1M_2}{M_1 + M_2} \qquad V_R^2 \text{-----------------------------------(7)}$$

Resume of Formulas:

(1) $M_1V_1 = M_2V_2$

Ram and bolster velocity are inversely proportional to their masses.

(2) $M_1A_1 = M_2A_2$

Ram and bolster acceleration are inversely proportional to their masses.

(3) $E_1M_1 = E_2M_2$

(4) $E = E_1 + \frac{M_1E_1}{M_2} = E_1\ (1 + \frac{M_1}{M_2})$

(5) $V_1^2 = \frac{2E}{M_1\ (1 + \frac{M_1}{M_2})}$

(6) $V_R = V_1 + \frac{M_1V_1}{M_2} = V_1\ (1 + \frac{M_1}{M_2})$

(7) $E = \frac{\frac{1}{2}M_1M_2}{M_1 - M_2} \qquad V_R^2$

(8) $\frac{M_1M_2}{M_1 + M_2} = M_E$ (M_E is defined as the equivalent mass of the machine. The ram mass equivalent to a specific velocity (V_R) at energy (e) if the bolster were stationery.

All of the excess energy of the traveling ram is absorbed by the momentum of the bolster moving in the opposite direction, this feature enables the machine to be installed on a floor which need only support a little more than the actual weight of the machine.

During the state-of-the-art survey in the first phase of this contract, the reports and visits to plants using the rubber pad process to produce parts for missiles and aircraft brought out the fact that the conventional location of the rubber pad was in the upper ram and the tooling in the lower bolster. This is true of the drop hammer, Ceco Stamp and hydraulic presses. Because the test program was carried out on a horizontal high energy rate metal forming machine, it was not possible to investigate the effects of the location of the pad and tooling on the use of the machine from a production standpoint.

Discussion of the production application evaluation of the prototype machine at the Fort Worth Division of the General Dynamics Corporation brings out the need for a complete investigation of the merits and drawbacks of each location of the rubber pad and tooling.

It will be shown in a later discussion under "Velocity" that to mount the rubber pad in the ram presents serious design problems. To mount the rubber pad in the bolster seems like a practical approach, but presents some loading difficulties that may be eliminated if the prototype machine was inverted so that the bolster mass was on top and the ram, when fired, traveled vertically upwards, carrying with it the blank into the rubber pad.

This arrangement would require the extension of the frame to support the large bolster mass and to provide stability to the whole machine.

ENERGY

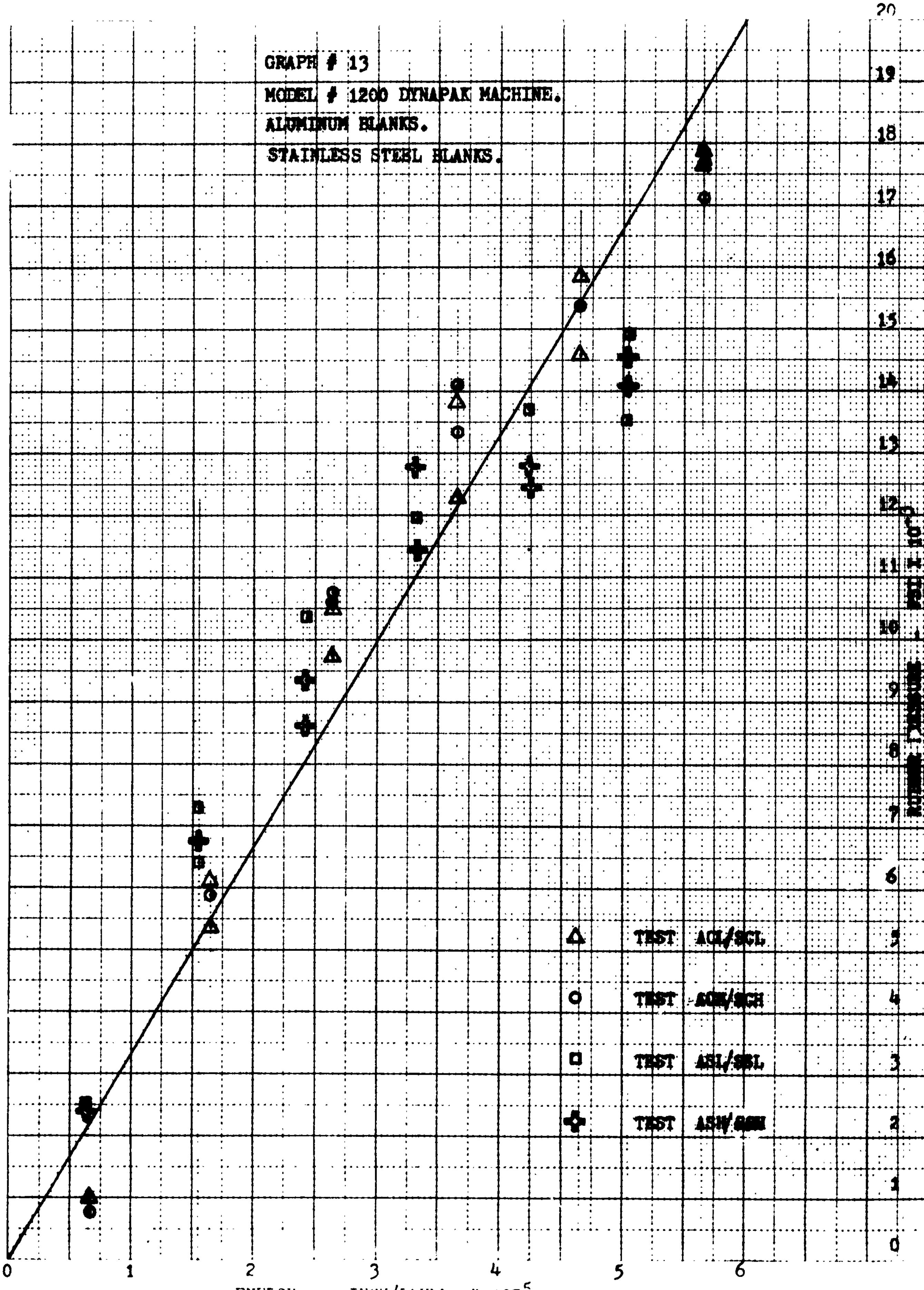
There is every evidence, as described under the heading "Effect of Energy Variation on Formability", that the predominant factor governing formability is the high rubber pressure obtained by high energy levels. Graph No. 13 shows the rubber pressure in psi plotted against energy in inch pounds, for both shrink and stretch tooling.

It will be seen that for the two types of tooling used that approximately 300,000 inch pounds was required to produce a rubber pad pressure of 10,000 psi, equivalent to 2,666 inch pounds per square inch of the rubber pad.

The deviation in the graph from its straight line characteristics which is evident above 300,000 inch pounds is due to the "drop off" in instrument response at the higher acceleration levels.

As specified in the contract, the prototype machine will be designed to produce 20,000 psi, over the complete area of 452 square inches, which is equivalent to a diameter of 24 inches. By extrapolation, it can be seen that to achieve this 20,000 psi, a maximum energy level of 2,400,000 inch pounds will be required, resulting in 5,333 inch pounds per square inch, over the complete area of the rubber pad.

In the series of tests in which the energy and consequently, the rubber pressure was varied, it would appear that 20,000 psi is considerably in



GRAPH # 13
MODEL # 1200 DYNAPAK MACHINE.
ALUMINUM BLANKS.
STAINLESS STEEL BLANKS.
TEST ACL/SCL
TEST ACH/SCH
TEST ASL/SSL
TEST ASH/SSH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
PSI X 10

excess of the expected normal usage of the prototype machine, and that 10,000 psi will more closely approximate the normal operating pressures in the rubber pad. The high energy rate machine used throughout the test program had a low bolster to ram mass ratio, consequently, considerable energy was expended in the elongation of tie rods and machine components. The prototype machine, however, will have a high bolster to ram mass ratio resulting in a more efficient use of the available energy.

This will result in a proportionately lower energy release requirement to achieve the desired rubber forming pressure. Basing the design on the energy levels, as determined in the test runs, will be conservative.

VELOCITY

The results of the test program where the ram velocity was varied are covered under the heading, "Effect of Velocity Variation on Formability".

It will be seen that for velocities from 404 to 622 inches per second, which were obtained by varying the ram mass, that very little improvement in formability was achieved.

Having already established an energy level of 2,400,000 inch pounds for the prototype machine, as the required energy to achieve 20,000 psi rubber pressure, and using the basic energy equation:-

$$E = \tfrac{1}{2} M V^2$$

which, because the proposed prototype machine has an opposed mass system, becomes:

$$E = \tfrac{1}{2} M_e V_r^2 \qquad \text{------------------------(7)}$$

where M_e = the equivalent mass, being the product of the ram and bolster mass, divided by their sum, and V_r = relative velocity, or the sum of the ram and bolster velocities.

From this equation, it can be seen that the relative velocity of the machine is:-

$$V_r = \sqrt{\frac{2E}{Me}} \qquad \text{------------------------(9)}$$

First consideration was given to mounting the rubber pad in the ram.

Preliminary design investigations show that to contain a rubber pad 24 inches in diameter x 12 inches thick into the ram would require a ram in excess of 6,000 pounds weight, and of a complex design, in order to withstand not only the bursting stresses as a direct result of the high rubber pressures, but also the superimposed inertia forces due to high accelerations at impact.

Again referring to the energy equation, and with an energy of 2,400,000 inch pounds, it can be seen that a ram velocity of only 550 inches per second would be obtained if the weight were to be 6,000 pounds.

It becomes apparent that a more practical approach to the design of the prototype machine is to have the rubber pad container integral with the bolster, an ideal location because of its mass, proportions and consequent lower accelerations.

The ram becomes a striking mass, directly propelled by an energy source so as to store the major energy of its blow as kinetic energy.

A typical ram configuration for the prototype machine is shown in Figure No. 13.

The weight of this ram must be such that it will result in the required striking energy at the desired impact velocity.

The practical minimum design weight of the ram for the prototype machine is approximately 3,000 pounds. Using the energy equation and a maximum energy of 2,400,000 inch pounds, it will be seen that the relative velocity between the ram and bolster is 825 inches per second, if we assume a reasonable bolster weight/ram weight ratio of 10:1.

With a ram face of 452 square inches, equivalent to 24 inches diameter and a pressure intensity of 20,000 psi from the rubber pad, the resulting load is 9,040,000 pounds. This value, divided by the ram weight, will give some indication of the deceleration encountered upon impact at maximum energy levels.

For a 3,000 pound ram, the deceleration would be about 3,000 g's. The striking end of the ram must be designed and proportioned so as to be capable of withstanding not only the 9,040,000 pound end-load created by the deceleration of 3,000 g's, but, in addition, transient stress effects resulting from shape change.

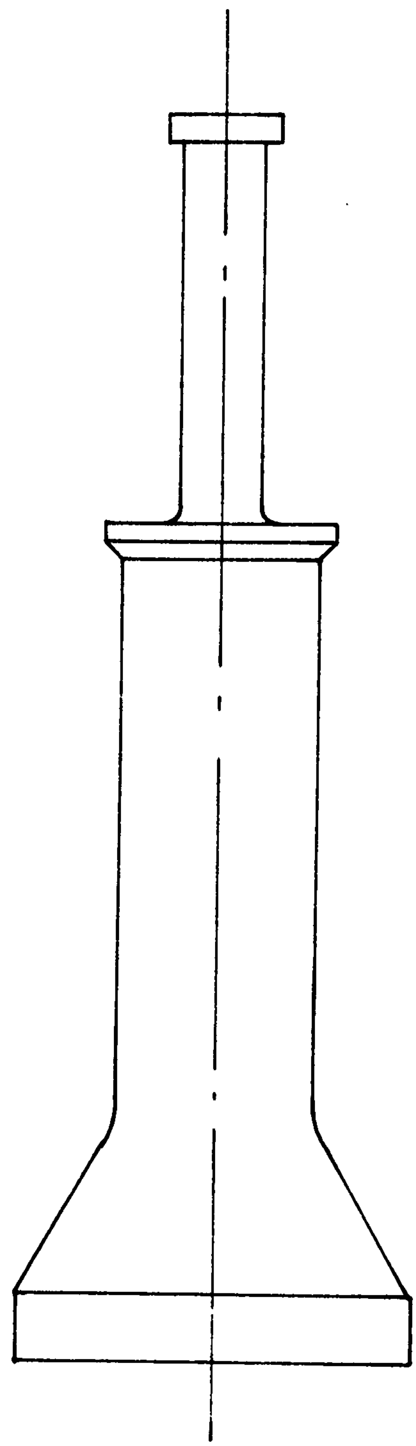
To better illustrate the definite relationship between ram velocities and ram weights, Graph No. 14 shows that ram weight in pounds plotted against ram velocity in inches per second, and Graph No. 15 shows deceleration of ram in g's plotted against ram velocity in inches per second. Both graphs are derived from:-

$$M = \frac{2E}{V2} \qquad \text{---------------------------------} (10)$$

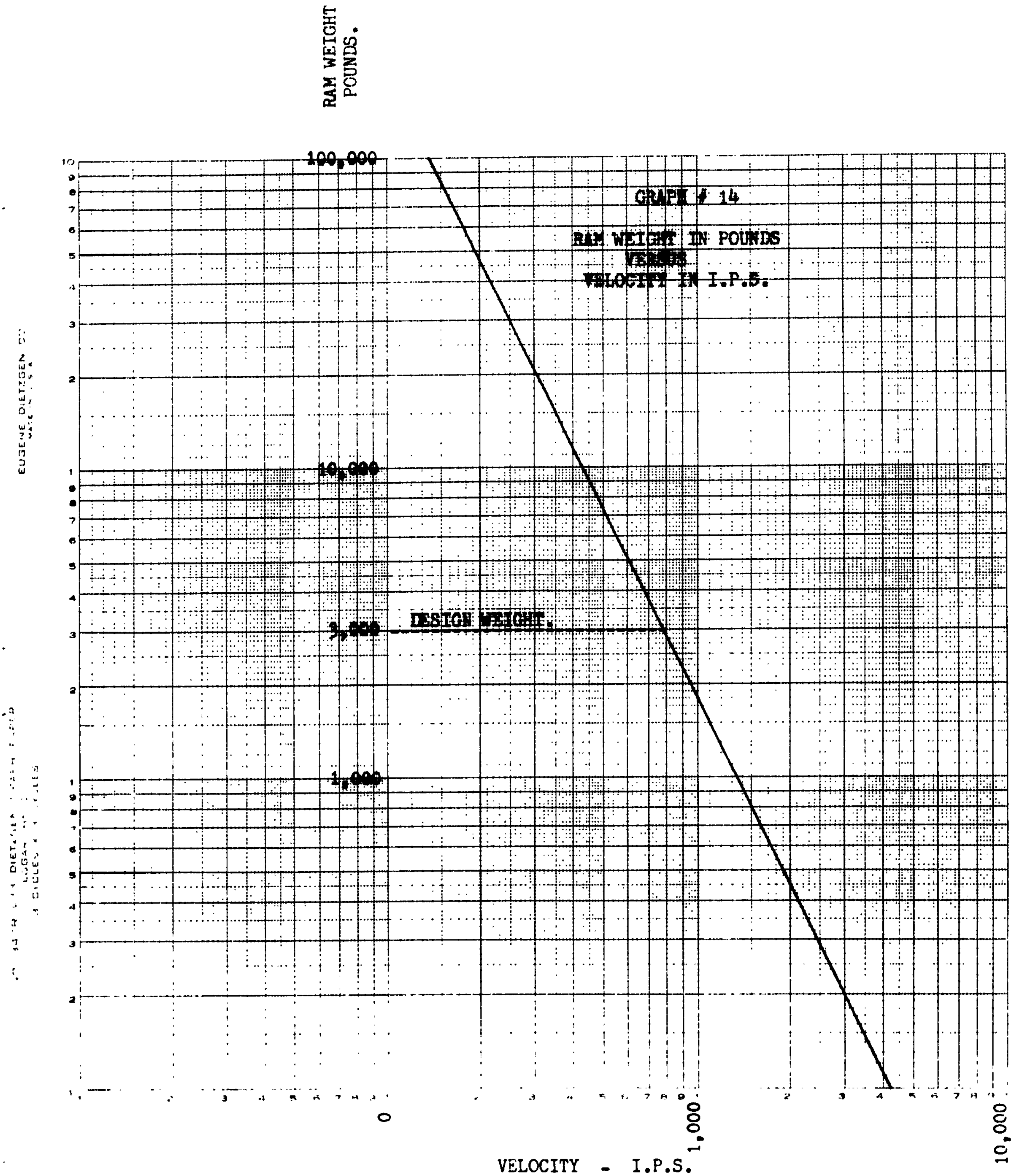
where E is 2,400,000 inch pounds.

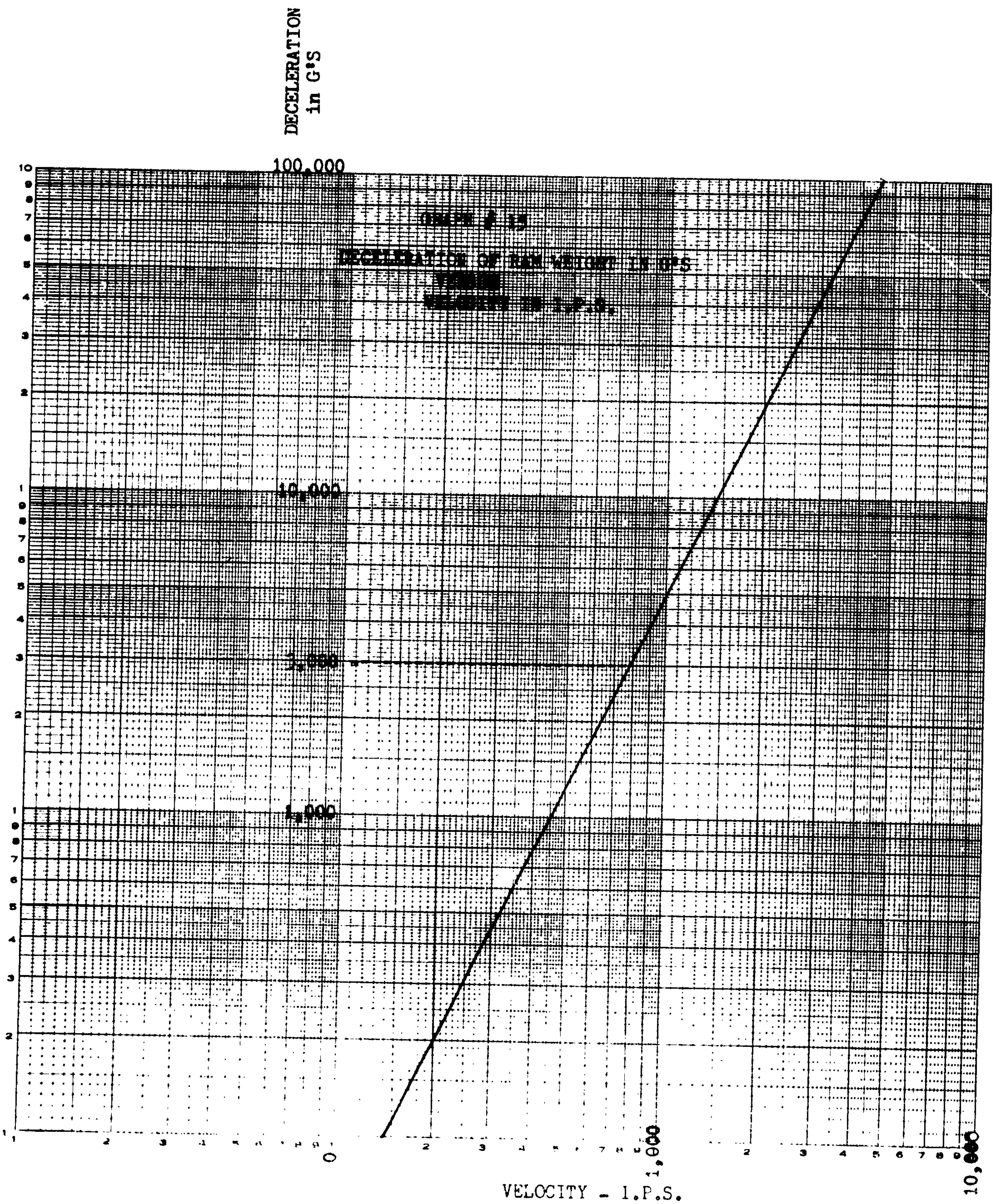
Even if higher velocities than the proposed velocity of 825 inches per second were beneficial to formability, the high g's associated with high velocities impose some definite limitations on the ram configuration, particularly on its length.

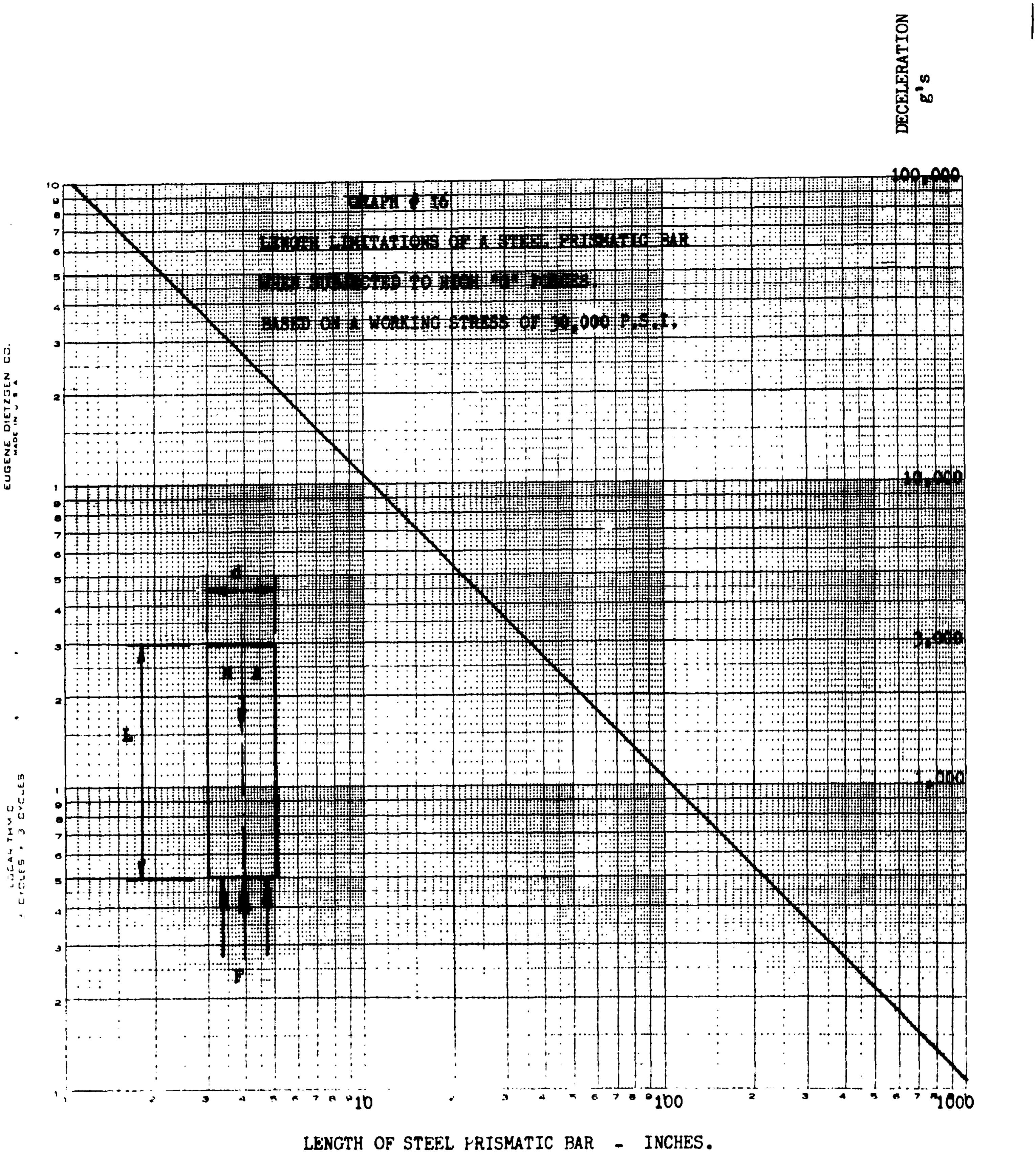
FIGURE NO. 13



RAM


RAM WEIGHT POUNDS.
GRAPH # 14
RAM WEIGHT IN POUNDS
VERSUS
VELOCITY IN I.P.S.
100,000
10,000
3,000
DESIGN WEIGHT.
1,000
0
1,000
10,000
VELOCITY - I.P.S.


DECELERATION
in G'S
100,000
GRAPH # 15
DECELERATION OF RAM WEIGHT IN G'S
VELOCITY IN I.P.S.
10,000
3,000
1,000
0
1,000
10,000
VELOCITY - I.P.S.



DECELERATION
g's
LENGTH LIMITATIONS OF A STEEL PRISMATIC BAR
100,000
10,000
3,000
1,000
L
F
10
100
1000
LENGTH OF STEEL PRISMATIC BAR - INCHES.
EUGENE DIETZGEN CO.
MADE IN U.S.A.

Consider a steel prismatic bar of length L and diameter D and assume a working stress S of 30,000 psi and p = density = .283.

Now $F = .7854d^2 S = Ma = .7854d^2 L p (g's)$.

$$\therefore S = L p (g's)$$

$$\text{then } 30{,}000 = L \times .283 \times g's$$

$$106{,}000 = L\, g's$$

$$L = \frac{106{,}000}{g's} \qquad \text{------------------------(11)}$$

Graph No. 16 expresses this equation and shows the length of a prismatic steel bar plotted against deceleration in g's. It can be readily appreciated how destructive high g's can be on large machine elements. If, for example, the g's were doubled, as they would be if the velocity were increased by 33%, then the length would be limited to about eighteen (18) inches, which is an impractical length, in view of the size of equipment being developed.

TEST TOOLING

The test tooling used in the program was designed to be used in existing high energy rate machines. The tooling was designed to accommodate a rubber pad 12 inches in diameter and 5 inches thick. Provision was made for mounting form blocks of various sizes and shapes, within the diameter limitation of the rubber pad container, although the test programs were planned to use only two form blocks, for stretch and shrink flanges, for formability evaluation.

All of the tooling was made of 4340 Steel, heat-treated to 36-40 Rockwell C, to permit machining if alterations became necessary.

The assembly of the test tooling used in all of the test programs is shown on Figure 3. In this drawing, the form block, 4037, used to form shrink flanges, is shown on the right half of the cross-section. The form block, 4038, used to form stretch flanges, is shown on the left half of the cross-section.

The rubber pad container, 4031, has a recess 12 inches in diameter and 6-1/2 inches deep to contain the rubber pad. A "lead-in" is formed by having the first 1/2 inch of the cavity machined on a 10 degree taper with a 1/8 inch radius on the corner. This is to guide the punch into the container.

This container is fastened to the bolster of the machine with six (6) 3/4 inch cap screws. One of the tapped holes in the bottom of the container has a 1/4 inch hole drilled through into the cavity containing the rubber pad. This hole permits the escape of the trapped air when the rubber pad is pressed into the container and is also used to admit compressed air to remove the pad from the container.

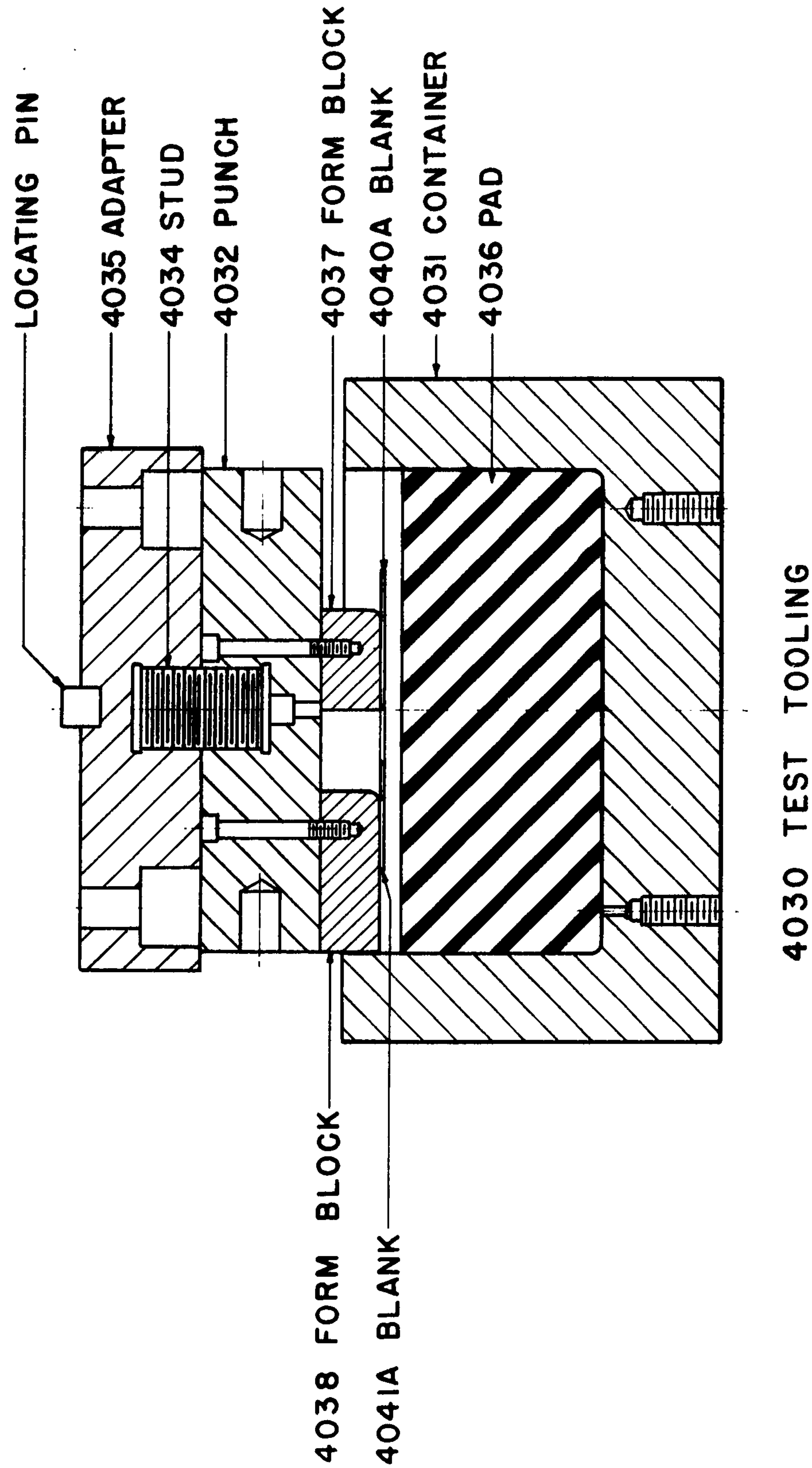

LOCATING PIN
4035 ADAPTER
4034 STUD
4032 PUNCH
4037 FORM BLOCK
4040A BLANK
4031 CONTAINER
4036 PAD
4038 FORM BLOCK
4041A BLANK
4030 TEST TOOLING

FIGURE 3

The adapter, 4035, is fastened to the ram of the machine with six (6) 3/4 inch socket head cap screws and is located centrally on the ram by the locating pin shown on the drawing. This adapter is provided with several sets of counterbored holes used to mount the container on the rams of any of the machines.

The punch, 4032, is mounted on the adapter, 4035, by means of ı threaded stud, 4034, to allow quick changing of the punch and the form blocks mounted on the face of the punch. This punch has several sets of counterbored holes to mount the various form blocks on its face. This method of mounting the form blocks was chosen so that the working face of the form blocks would have a smooth surface unbroken by holes or boltheads.

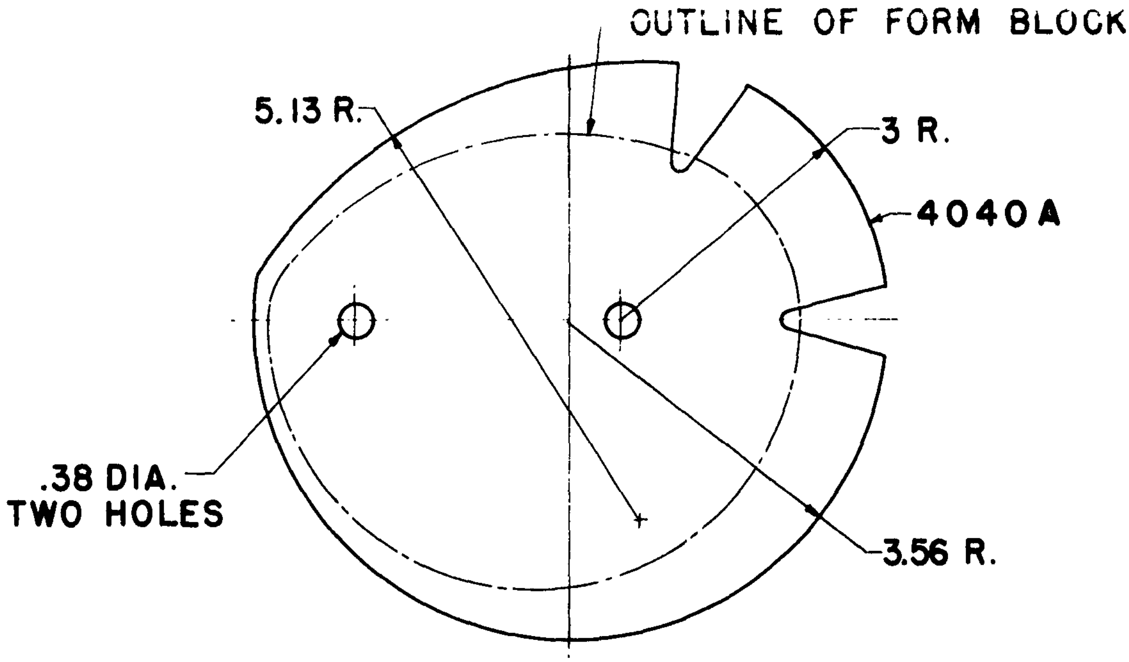
The form block for forming shrink flanges, 4037, is shown in detail on Figure 4, with the blank used for the shrink flanges, 4040A. The form block was designed to have four radii, 1, 2, 3 and 4 inches. A uniform bend radius of .13 inches was machined around the entire circumference of the form block. The working face, the bend radius, and the sides of the form block were polished. The test blanks were located on this form block by two (2) .375 inch diameter locating pins pressed into the block. This block was mounted on the face of the punch with six (6) 3/8 inch socket head cap screws.

The form block used to form stretch flanges, 4038, is shown in detail on Figure 5 with the test blank used for the stretch flanges, 4041A. This form block has a 4 inch diameter hole through the center to form stretch flanges with a 2 inch radius. The bend radius of .13 inches is machined around the entire circumference of the 4 inch diameter hole. The working face, the bend radius, and the 4 inch diameter hole were polished. Two (2) .375 inch diameter pins were pressed into the form block for locating the test blanks. This form block was mounted on the face of the punch, 4032, with six (6) 3/8 inch socket head cap screws.

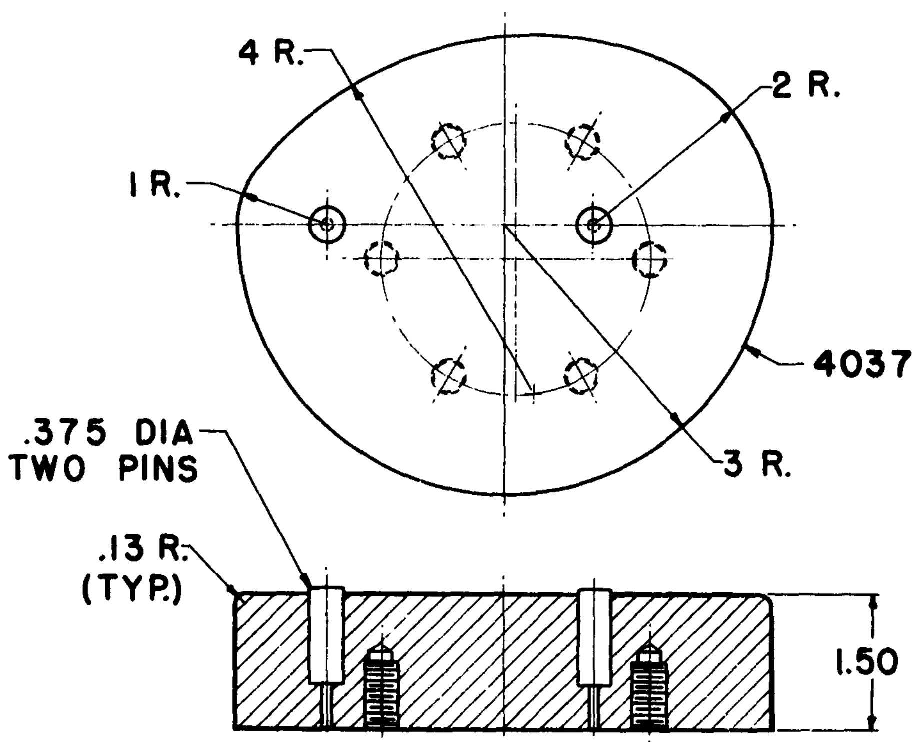
RUBBER PADS

It was decided to use a conventional rubber pad as a pressure medium during the two planned test programs. This pad, 4036, is twelve (12) inches in diameter and five (5) inches thick with a 1/8 x 45 degree chamfer on each end. This pad is pressed into the container, 4031, using the ram of the test machine. This operation is done slowly and the pad is retained in the container by the press fit of the rubber in the cavity. Removal was accomplished by introducing compressed air between the rubber pad and the bottom of the cavity in the container. No difficulty was experienced with either the introduction or removal of the pads.

Previous work with rubber pads of laminate construction at high velocities had disclosed failures of the pad occurring at the cemented joints between the laminations and for this reason, a solid pad was used in the test programs.

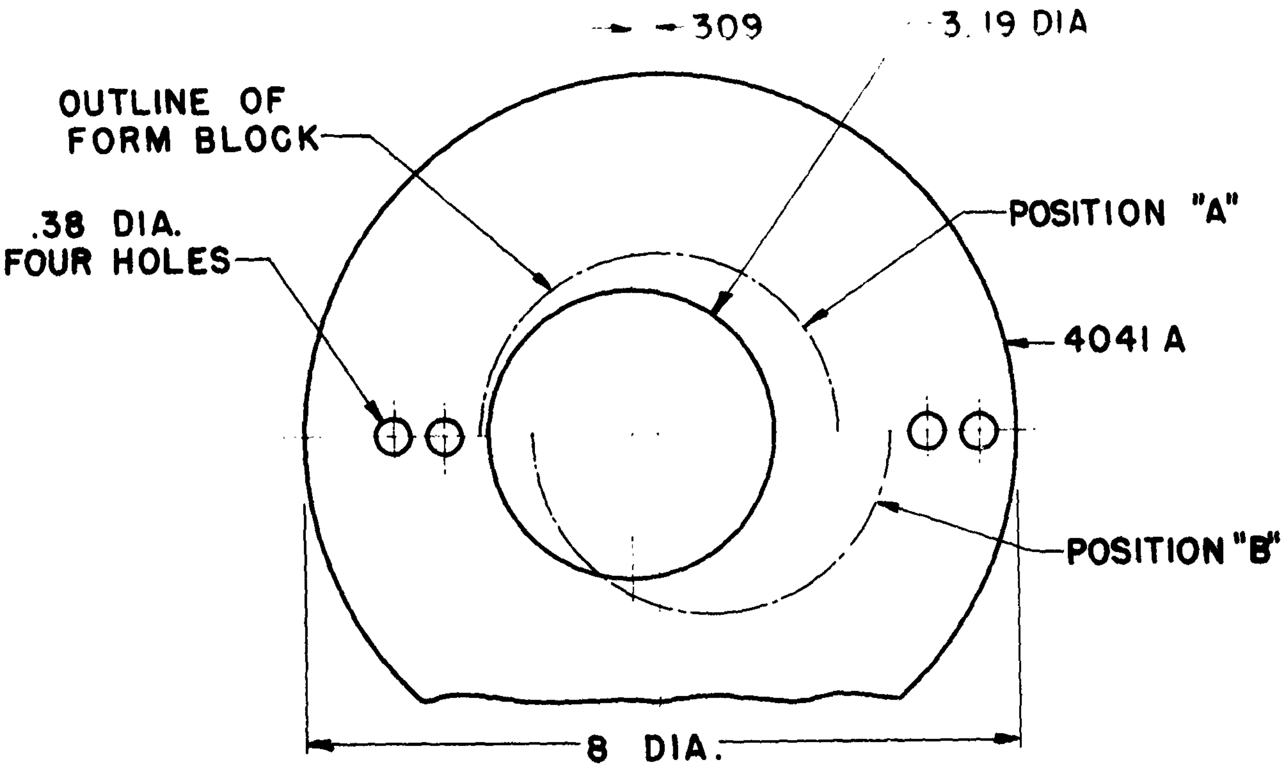


TEST BLANK FOR SHRINK FLANGES

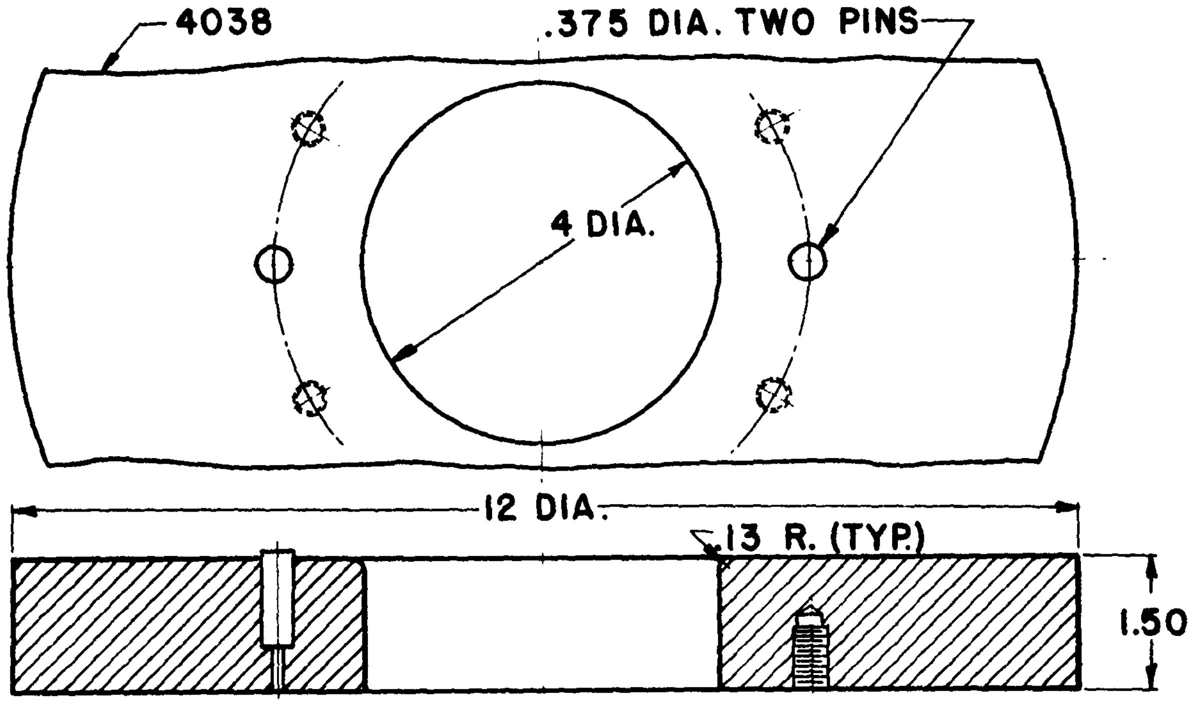


FORM BLOCK FOR SHRINK FLANGES

FIGURE 4



TEST BLANK FOR STRETCH FLANGES



FORM BLOCK FOR STRETCH FLANGES

FIGURE 5

Thirteen manufacturers, most having experience in the production of rubber pads for use in the Guerin Process, were asked to furnish bids for the pads to be used in the test programs, with their recommendations as to the compound and Durometer hardness to be specified.

The five pads required for the test programs were secured from the A. G. Mosites Company, Fort Worth, Texas. These pads were made of Mosites Compound No. 651-70 and the Durometer hardness of the pads supplied was eighty-five (85).

The photograph at the top of Figure 6 shows two Mosite Pads. The surface of an unused pad is shown at the right and the face of the pad after forming fifty (50) shrink flanges is shown at the left.

TEST BLANKS

Test blanks were made of two materials. The aluminum blanks, in both .032 and .060 thicknesses, were made from 2024-0, Specification QQA-362 aluminum alloy.

The stainless steel test blanks were made from MIL-S-5059A in two thicknesses, .028 and .063.

The test blanks were manufactured at the Convair Division of the General Dynamics Corporation, San Diego, California, using the same methods as used to make the blanks for the production parts made on the conventional rubber pad presses in this plant.

The surface finish of the machined edges of the blanks used in the test programs was the same as the surface finish prevailing in the normal production practices in the airframe industry so that any adverse effects, particularly in the forming of stretch flanges, would become apparent.

Test blank 4040A, used to form the shrink flanges, is shown in detail on Figure 4. The outline of the form block used, 4037, is shown by broken lines so that the type of part formed, with a varying flange height, may be visualized.

As a result of preliminary forming tests, it was found advisable to incorporate two relief notches, located at the tangent points of the 2 inch radius with the 3 and 4 inch radii on the form block. While these notches rendered the forming of the part at the 2 inch radius of little value in the study of formability, their presence did make the evaluation of the forming of the blank over the 3 and 4 inch radii of greater value.

The test blank used to form the stretch flange, 4041A, is shown in detail on Figure 5. It will be noted that the form block, 4038, used to form the stretch flanges, is shown in two positions by broken lines. It was discovered in the preliminary forming tests that the thinnest (.028) stainless steel stretch flange was formed satisfactorily with the form block in position "A" because the flange

AFTER 50 PARTS NEW PAD

A. G. MOSITES COMPANY COMPOUND 651-70

AFTER 9 PARTS NEW PAD

KIRKHILL RUBBER COMPANY UNCURED COMPOUND 7-B-884

FIGURE 6

height was too low. Two (2) additional .38 inch diameter locating holes were added to these test blanks to permit offsetting the blanks on the form block and a higher flange could be formed.

Each blank was identified as to material, thickness and type of flange to be formed by a code number stamped on the blank. This code number was used to identify the individual test run on all of the records secured; the tape from the Minneapolis-Honeywell Visicorder, the photographs taken of the oscilloscope traces, and the high speed motion pictures taken to secure a record of the velocities attained.

LUBRICATION

The state-of-the-art survey conducted during the first phase of this contract disclosed the fact that the use of a lubricant on the surface of the blank was general throughout the aerospace industry. In the discussion of rubber pad forming of flanges, one reference (5) states, "Splitting limits for any material may be increased by lubricating the surface being formed".

It was decided, however, that the use of lubricants would introduce an additional factor into the evaluation of the effects of energy and velocity on formability in the test programs and lubrication was not used. The test programs were designed to obtain important information for the setting-up of basic design parameters for the prototype machine and were not intended to be an exhaustive investigation of formability.

INSTRUMENTATION - VELOCITY

Previous experimental work with the same test machine made use of a Sanborn Velocity Transducer to record the velocities while extruding materials. This work results in much lower shock loadings and the Sanborn Velocity Transducer performed satisfactorily in this application.

At the beginning of this series of test programs, the same Sanborn Velocity Transducer was mounted on the end plate of the machine with Formica clamps. The magnetic core of the transducer was attached to the ram with an aluminum rod to avoid interference with the electrical characteristics of the instrument. The high shock loads encountered on the first instrumentation test run damaged the transducer when the inner bobbin and winding was torn from the outer housing.

A second velocity transducer was secured from the same source and mounted with an improved Formica clamp designed to support the inner bobbin. This instrument was also damaged in the same manner as the first transducer on its first test run.

It was then decided to make use of high speed motion picture equipment to photograph a scale attached to a rod of the machine and a pointer attached to the ram. The individualframes of the high speed motion picture film could then be analyzed and the velocity of the ram determined and the acceleration

measurements could also be substantiated. A photograph of the scale and pointer is shown on Figure 7.

A Wollensak Fastex 16mm High Speed Camera was used with high intensity lighting and a Fastex Goose Control Unit. This control unit made it possible to start the camera and then start the stroke of the DYNAPAK high energy rate metal forming machine after the camera had accelerated to the desired speed range of 1500 to 1700 pictures per second. This control unit also provided a timing "blip" on the film for time measurement.

Analysis of the film taken showed that the ram traveled the 5-3/4 inches from rest to the contact of the test blank with the face of the rubber pad in time intervals ranging from 46.6 milliseconds at the lowest velocity to eleven (11) milliseconds at the highest velocity used in the test programs.

The velocities of the ram, at the instant that the test blank touches the face of the rubber pad, ranged from 216 to 622 inches per second. The ram continued to advance, forming the test blank, for intervals of 1.3 milliseconds, at the highest velocity recorded, to 7.75 milliseconds at the lowest velocity.

INSTRUMENTATION - ACCELERATION

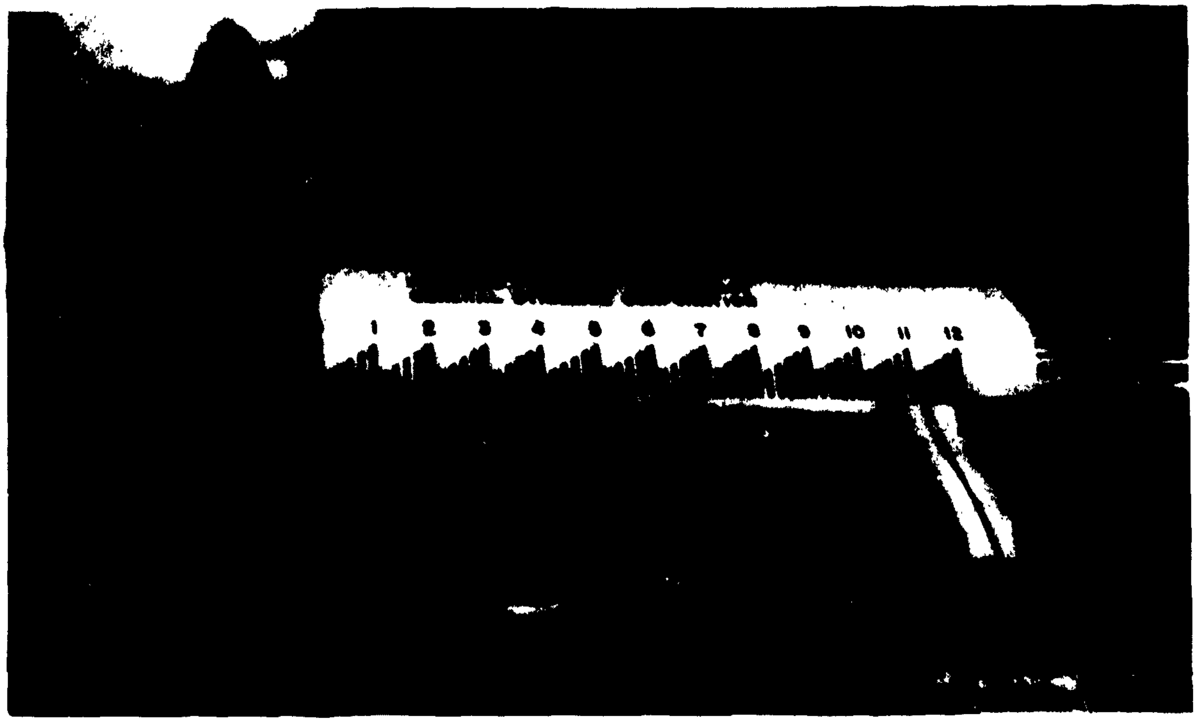
Two Endevco accelerometers, at different amplifications, were used to record the acceleration of the ram. These accelerometers were mounted on the column cap on the end of the ram. The signal from each accelerometer was fed into an individual amplifier and impedance matching unit and from these units into a Minneapolis-Honeywell Visicorder. This oscillograph was provided with a 500 cycles per second time signal to aid in analysis of the record on the tape.

The amplification of the first accelerometer was too high for the recording characteristics of the Minneapolis-Honeywell Visicorder during the forming pulse but its increased sensitivity was used to record the acceleration of the ram from rest to the instant of the contact of the test blank with the face of the rubber pad. This record was used to check the calibration of both accelerometers with the known acceleration characteristics of the test machine.

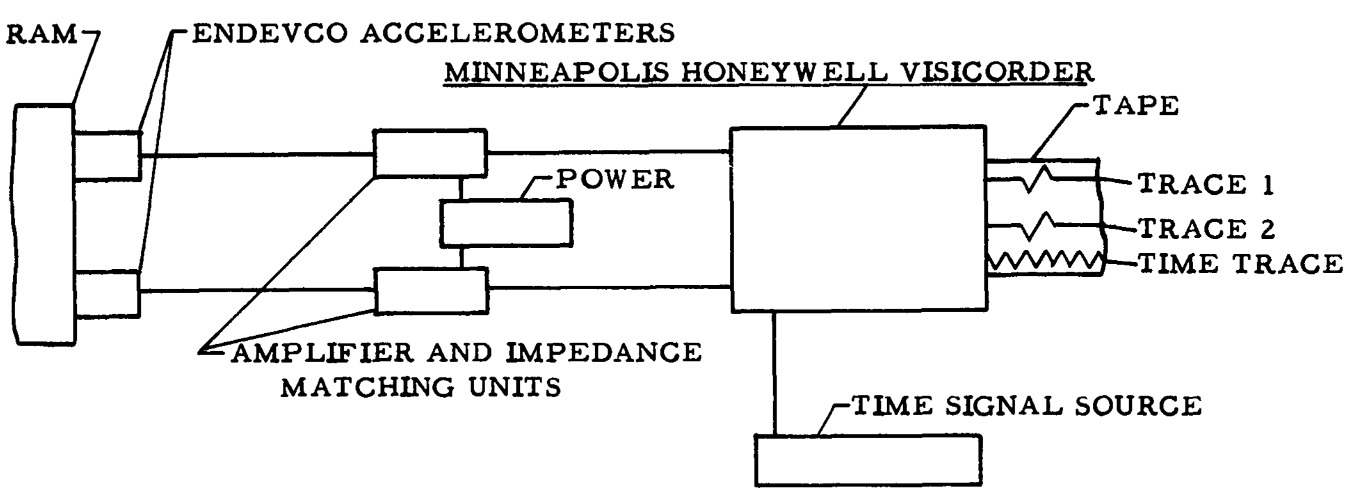
The amplification of the second accelerometer was lower and was used to record the forming pulse.

It is necessary at constant energy and a constant force versus displacement curve that the tool loading be constant. When tool loading is constant, acceleration is necessarily inversely proportional to the mass of the ram and tooling.

The recorded acceleration records followed this relationship within expected experimental scatter at the three lowest velocity levels of the varied velocity tests but deviated seriously at the two highest velocities.



PHOTOGRAPH OF SCALE AND POINTER



INSTRUMENTATION

FIGURE 7

As a check of the acceleration records, high speed movie films were analyzed to determine if an important energy variation occurred. It was determined that the blow energy was indeed constant.

A series of test runs was repeated varying the velocity at constant energy. This series of test runs was recorded on the Visicorder oscillograph, as before, and also on two oscilloscopes. The trace on the oscilloscopes was recorded with a Polaroid Camera.

This series of tests disclosed the fact that the response capacity of the galvanometers in the Minneapolis-Honeywell Visicorder was insufficient to follow the very short pressure pulse times encountered at the two highest velocities used.

The oscilloscope traces were clouded by the existence of high frequency resonant ringing, but they did confirm the fact that the project acceleration levels, based on the constant blow energy and ram weight variation, were substantially correct. A graphical analysis of the high speed motion picture records also substantiated the correctness of expected levels. The information from the record of the Minneapolis-Honeywell Visicorder was substantially correct at the three lower levels of acceleration.

ENERGY VARIATION

The Model 1200 DYNAPAK high energy rate metal forming machine used in the test program is actuated by compressed gas. The energy developed by the machine, with a constant stroke, varies with the pressure of the gas used to energize the machine. The pressure of this gas is under the direct control of the operator and thus, the energy may be varied, as desired.

In forming the shrink flanges, the following gas pressures and resultant energies were used:

Gas Pressure - psi	Energy - inch pounds
250	67,700
400	166,000
550	262,500
700	365,300
850	465,000
1,000	565,000

When forming the stretch flanges, the stroke changed slightly and the following gas pressures and resultant energies were used:

Gas Pressure - psi	Energy - inch pounds
250	64,500
400	154,500
550	242,000

Gas Pressure - psi	Energy - inch pounds
700	332,000
850	424,000
1,000	504,000

VELOCITY VARIATION

When the gas pressure and the stroke of the test machine are held constant, the velocity may be varied by changing the weight of the moving ram.

The ram weight may be readily changed on the machine used for the test program because the ram in this machine is made of a series of laminated steel discs, or ram weights, that may be removed and replaced as desired. This ram constructed may be seen in the photograph on Figure 7.

In forming the shrink and stretch flanges, the gas pressure was held constant at 700 psi, the stroke remained the same, the resultant energy was 365,300 inch pounds, and the velocity varied as the weight of the ram changed, as follows:

Ram Weight, Plus Tooling, Pounds	Velocity, Inches per Second
2376.5	404
1845.5	430
1491.5	452
960.5	540
606.5	622

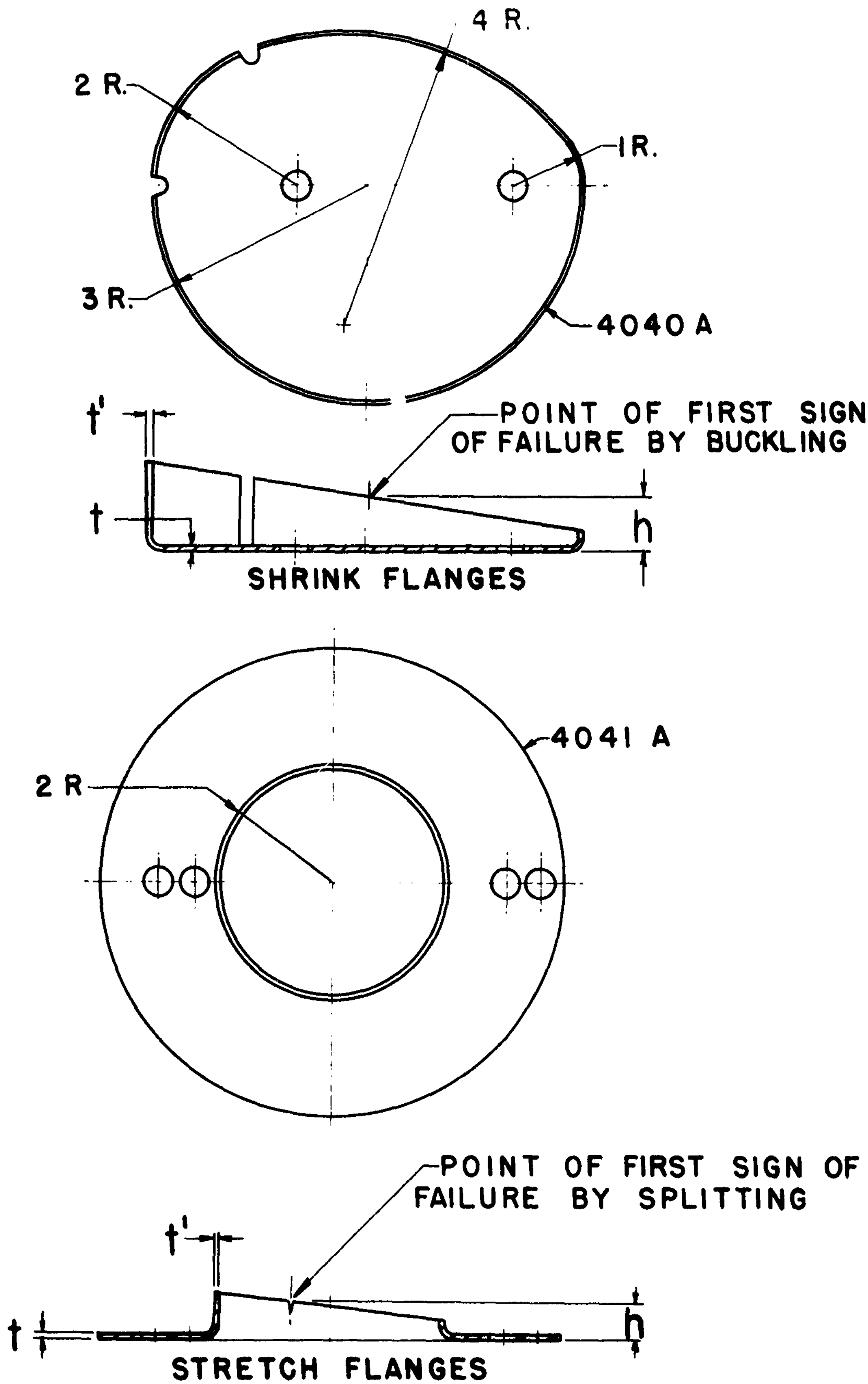
FORMABILITY MEASUREMENT

It was desirable to have a means of measuring the formability attained with both the shrink and stretch flanges that would enable a comparison to be made between the effects of energy and velocity on the two materials, aluminum and stainless steel alloys, in the two thicknesses used in the test blanks.

The method used is shown in Figure 8 as applied to both the shrink and the stretch flanges.

The original thickness of the blank, "t", was measured with a micrometer before the blank was formed. The value of "t" used in the data represents an average of ten measurements taken around the circumference of the blank approximately 3/4 of an inch from the edge.

The maximum height of the flange formed, "h" was measured at the point where the highest satisfactory flange height was obtained. The point of maximum height in the case of the shrink flange was taken at the point where the first perceptible buckling became apparent. The point of maximum height in the stretch flange was taken at the point where the first sign of failure by the tearing of the metal occurred.



FORMABILITY MEASUREMENTS

FIGURE 8

A second reading of thickness, "t'", was taken after the test blank was formed. This measurement was taken with a micrometer, having balls on the anvil and spindle, at the point of maximum flange height, as determined above for "h". This measurement is an indication of the change in thickness after forming and is usually greater than the original thickness of the test blank in the case of shrink flanges and less than the original test blank thickness in the stretch flanges.

The value "R" is the radius of the form block in inches. In the case of the form block used to form the shrink flanges, 4037, two values of "R" were used, 3 inches and 4 inches. The other two radii on the form block, 1 inch and 2 inches, were not used in the formability evaluation. The configuration of the blank, in order to secure the varying height of flange, made the very low height at the one inch radius of little or no significance. The presence of the two relief notches, at the tangent points of the two-inch radius with the three and four-inch radii, made the evaluation of the flange height at this point of doubtful value. Preliminary forming tests had indicated the advisability of sacrificing these two measurements in favor of a blank contour that would produce the tapering flange and result in better formability evaluation.

From the measurements taken from the formed test blanks, the values of h/t and h/R were calculated and used with the springback to gage the formability achieved in the specimens.

ALTERNATE ENERGY SOURCES

Perhaps the most thorough investigation of energy sources for a high velocity rate metal forming machine was that carried out by the General Dynamics Corporation during the extensive program of research work that culminated in the introduction of the first high energy rate metal working machine to American Industry in 1958.

Included in this program was the design, construction, and the operation of high energy rate machines using several energy sources. These energy sources were being evaluted for use in a machine that could be safely and economically operated in any manufacturing plant.

The early work in this program (13) discusses the investigation of high pressure steam, compressed air, explosive powders, gas mixtures and diesel fuel. A machine was designed and built that used a 12 gage, specially loaded, shotgun shell for actuation. This machine incorporated a rubber pad and means for mounting form blocks to form sheet metal at higher velocities and rubber pressures. The rubber pads used in the test runs were rendered useless after five or six forming operations.

It is evident that, from comparison of the results of the current test work, catastrophic rubber damage was the result of excess energy resulting in extremely high rubber pressures.

The impact force obtained was regulated by varying the explosive charge. Powder charges of 66, 99, 135 and 150 grains were used. The use of the 150 grain charge damaged the machine and the report states, "Great care will have to be exercised in designing a full scale model to insure adequate safety".

A second report (14) discusses the difficulties encountered with the use of explosive charges and states, "The cylinder walls became galled, the piston ring broke, the guide pins were forced out of line and the guide bushings were difficult to keep in place."

In the final report (15) on the use of the machine actuated by a special shotgun shell, it is stated that the machine was only being used to demonstrate the principle and that it was intended to continue the investigation with a unit using two opposed hydro-pneumatic cylinders so designed that they could be released simultaneously.

During the experimental work with the opposed piston, hydro-pneumatic machine (17) the need for a rubber substitute became apparent and the machine was damaged during the tests.

Difficulty was also experienced with instrumentation limitations at the velocities and energies encountered.

A pneumatically operated machine was then constructed (16) and tested at the Convair Division of General Dynamics Corporation. It is significant that the previous difficulties with rubber, or the rubber substitutes (17), influenced the design of the new unit and use was made of water as a forming, or pressure, medium. Parts were formed successfully with this machine and development continued.

A unit was constructed (12) using a precharged high pressure mixture of propane and air, spark ignited, to drive a piston and ram. This machine was operated successfully but this source of energy was discarded. While the source of energy, propane gas, in the amounts used each time the machine was fired was relatively cheap, the compressed air used in each firing was lost increased the operating cost. Noise, when the mixture was ignited, was considered objectionable. Reliability was expected to be poor in service. These facts, combined with safety hazards, resulted in the abandonment of this energy source.

Investigation of the literature discloses the use of compressed gas (20) in a laboratory machine at the Moscow State University. A "striker", 3.858 inches in diameter, was fired through a tube by the sudden release of compressed gas. Various lengths of "strikers" were used with weights of 22, 44 and 66 pounds. Velocities up to 11,800 feet per second were obtained in this laboratory type machine.

A high loading rate testing machine is being developed (23) for the Picatinny Arsenal by the Hesse-Eastern Division of Flightex Fabrics, Inc. This machine is to be used for testing standard 1/4 and 3/8 inch ASTM tensile test specimens and as presently being used, has a 6 inch stroke and a capability of exerting a 15,000 pound load in approximately 7 milliseconds. This machine is actuated

by compressed gas and the rate of loading is controlled by the release of fluid trapped under the piston. This machine does not appear suitable for use as a high energy rate rubber pad forming machine, because of the problems associated with the release of the trapped fluid in a sufficiently short time to afford the required velocities and energies.

The Temco Hot Gas Actuator (24) was investigated as an energy source for the test programs planned for the first portion of this phase of the overall program outlined in subject contract. This hot gas actuator is located at the Ling-Temco Engineering Facility at Garland, Texas. This installation was originally designed to provide a high intensity thrust at low velocity and in the absence of any impact forces (25).

This machine was tested, under these conditions only, using powder charges such as to create gas pressures up to 3600 psi. This corresponds to a powder charge weight of approximately one (1) pound.

The machine consists of powder chambers, a piston and containing cylinder arranged in the present test configuration to react directly on a hydraulic unit serving as a controllable reaction device. No other provision exists to restrain the piston so as to allow a gas pressure build-up prior to initial motion of the ram.

The unit is mounted in a frame proportioned to contain the thrust forces developed in the low speed static test work but not so designed as to be capable of reacting the extremely high forces associated with impact forming at very high energy levels.

It is proposed by Temco that the actuator system be used to develop ram velocities up to 500 feet per second, impinge on the work to be formed, then be slowed to some lower velocity. For the velocity approaching 500 feet per second, this lower velocity is proposed at 300 feet per second. No plans have been made to dissipate the remaining kinetic energy after completion of the forming cycle. This problem is appreciable. A 500 pound ram will have a kinetic energy of 700,000 foot pounds at 300 feet per second. It is expected that extensive redesign of the facility would be required to include provision to dissipate this excess kinetic energy at force levels non-destructive to the equipment. Other problems could be expected to exist.

In summary, the problem of accelerating a ram in an impact process can be approached from several avenues. In the end result, it is unimportant to the metal forming process which is chosen, so long as the striking ram achieves the desired kinetic energy. The processes need be judged only on the basis of safety, economy, convenience, and controllability. Electric spark discharge and the detonating types of explosives have too short a time of energy release to be useful in driving a piston. The low explosive and hydrocarbon fueled devices are noisy and suffer in reliability, safety, and to a degree, in lack of convenient controllability (infinite adjustability). The compressed gas type of actuator provides the most adjustable, convenient and economical driving means of those studied.

ALTERNATE ELASTOMERS INVESTIGATION

When manufacturers of rubber products with experience in the production of rubber pads for use in the aerospace industry were asked to bid on the rubber pads for the test programs, one of the firms, the Kirkhill Rubber Company, Brea, California, suggested the use of an uncured rubber pad to better withstand the higher velocities and pressures to be used in the test programs.

Two laminated pads of uncured Kirkhill 7-B-884 forming rubber compound were furnished by this company, on a no-charge basis, for inclusion in the investigation of elastomers.

One of these pads was pressed into the container, 4031, using the form block, 4038, used to form the stretch flanges.

It was anticipated that the uncured rubber pad would not return to its original shape after the forming stroke had deformed the uncured rubber. The test pad was statically loaded to investigate this.

A static load was applied to the pad, 2000 psi, for approximately one minute, the ram retracted and the face of the uncured rubber pad examined. The center of the pad contained a raised portion 4 inches in diameter and 3/8 inch high, corresponding to the hole in the center of the form block used. This deformation or set was much less than had been anticipated. The pad was then used to form nine stretch flanges.

The parts were formed successfully although the center of the pad became somewhat chewed, as shown on the photograph at the bottom of Figure 6. The face of a new pad of uncured Kirkhill 7-B-884 is shown on the right side of the photograph for comparison.

Deformation of the surface of the pad did not prevent the forming of satisfactory parts. Some trouble was experienced with the tackiness of the surface of the uncured rubber, making the removal of the formed part difficult. The uncured rubber, as expected, had a greater tendency to extrude into the holes on the face of the punch.

It appears that the uncured rubber will form parts as readily as the cured rubber pad used in the test, but its tackiness and extrudability may present problems in production.

Another firm, the Dayton Rubber Company, Dayton, Ohio, through their representatives, the American Latex Products Corporation, Hawthorne, California, suggested the use of a urethane elastomer, DAYCOLLAN. Twelve inch diameter samples of the material were not available, but three 2-inch diameter samples, in three grades, were supplied for examination. These grades were: DAYCOLLAN 90, DAYCOLLAN 80, and a special formulation, 4277-26. These samples are too small for use with the existing tooling used in the test programs described earlier in this report.

A polyurethane material, ElastaCAST, manufactured by the Acushnet Process Company, New Bedford, Massachusetts, and distributed by the Standard Die Set Company of Providence, Rhode Island, was also investigated. This material is being used in metal forming operations at present, although the operation differs from the Guerin, or rubber pad process. In the application of this material to the test programs described earlier in this report, additional tooling would be required and separate containers for each part configuration would be needed.

This presents a different approach to the usual rubber pad process where the form blocks may be placed at different locations with respect to the rubber pad and several form blocks used at the same time. In the application of ElastaCAST, the surface of the pad is relieved by cuts or grooves, to suit the configuration of the part to be formed.

This approach lacks the flexibility of the normal rubber pad forming process. As mentioned in one reference (29), "The action of polyurethane is quite different from that of rubber, the basic component in the Guerin process, since it is effective only when its entire mass is put into action".

No ElastaCAST Pads were secured for the test programs described.

Work has been going forward with the use of water as a pressure medium. The parts shown on Figure 9 were made from .031" Zircalloy 4 and Type 304 Stainless Steel. The die and water container, shown on Figure 10, were mounted in a vertical high energy rate metal forming machine and production runs made of these parts.

The water-forming tooling is shown on Figure 11. The container is placed on the bolster of the machine, located by the round spud on the bottom. The container is filled with water to the level determined by the water vent hole.

The die is inverted on a bench, the lubricated blank placed on the face of the die and held in position with the blank holder. Six screws are used to fasten the blankholder to the die. The film of grease, used on the face of the blank, acts as a lubricant and also serves to prevent the entrance of water into the cavity in the die.

The die, with the attached blankholder and blank, is then inverted and placed in the container where it rests on the water, as shown in the cross-section on Figure 11. The ram of the machine strikes the top of the die and the part is formed by the water. The air in the cavity is displaced through the small air vents in the die.

Three different sized parts were formed, using three different dies and blankholders, with one water container in the machine.

During the production of these parts, it was discovered that the energy level was critical, too low an energy resulted in an incompletely formed part and too high an energy level ruptured the blank.

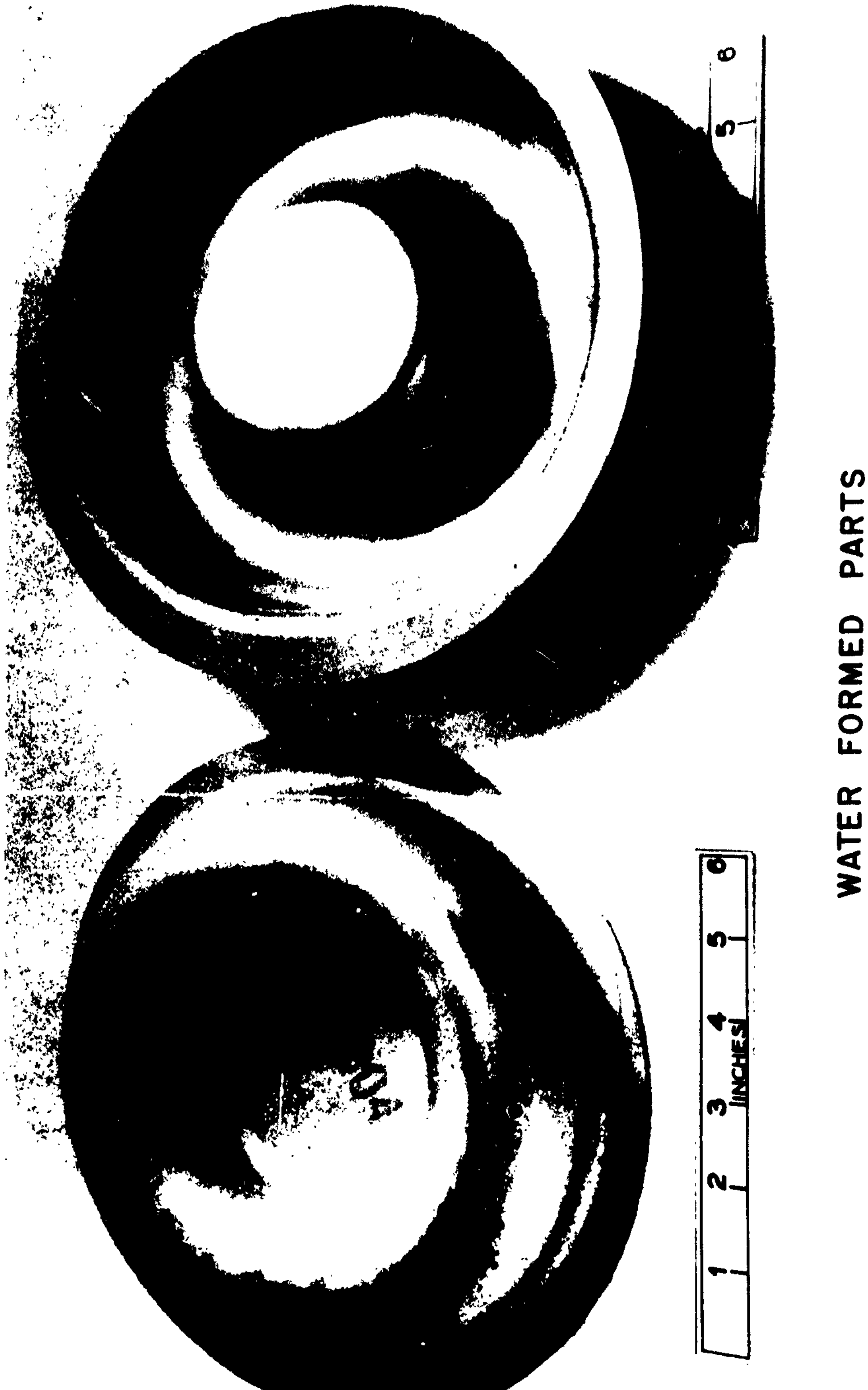
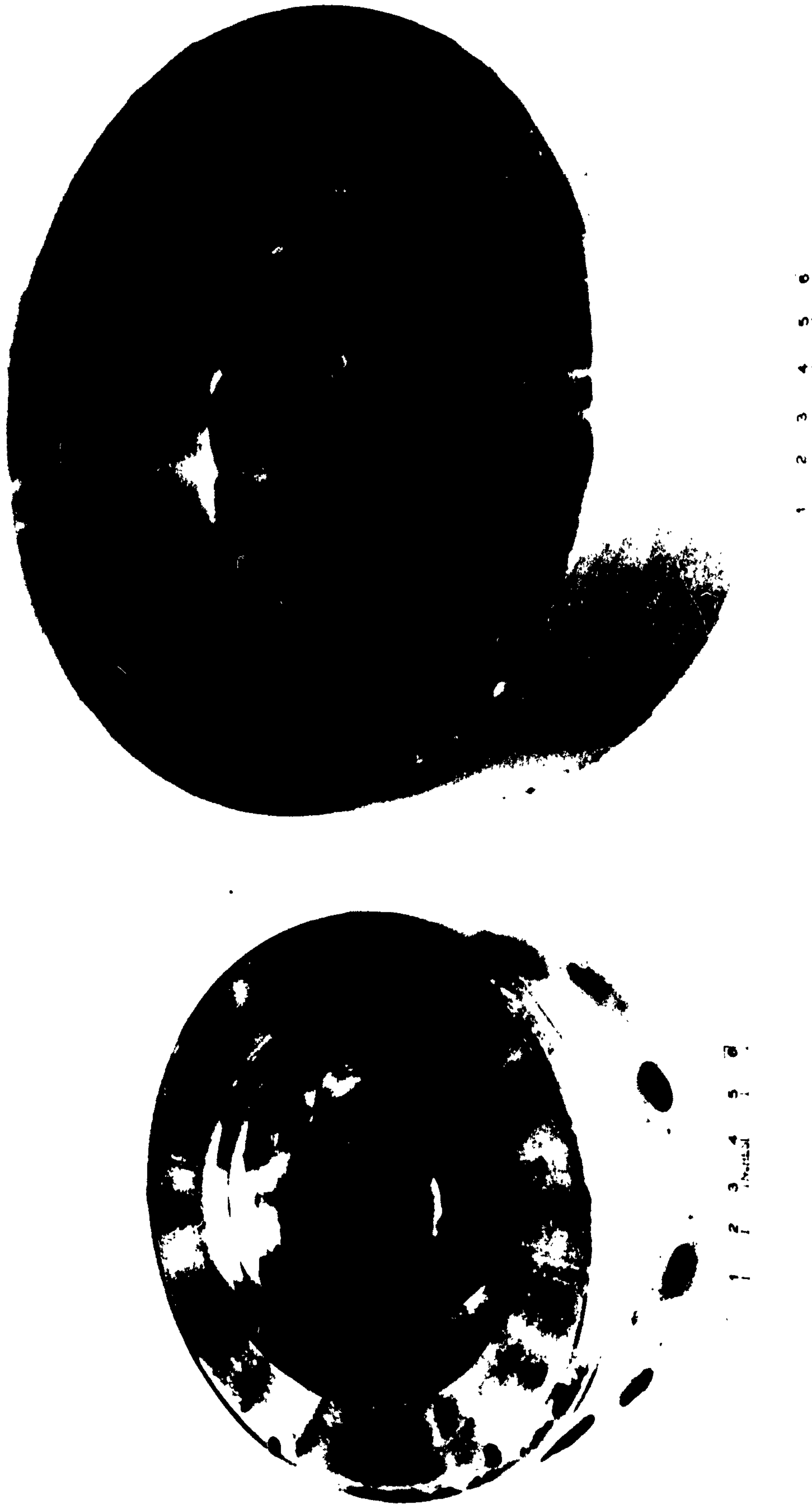
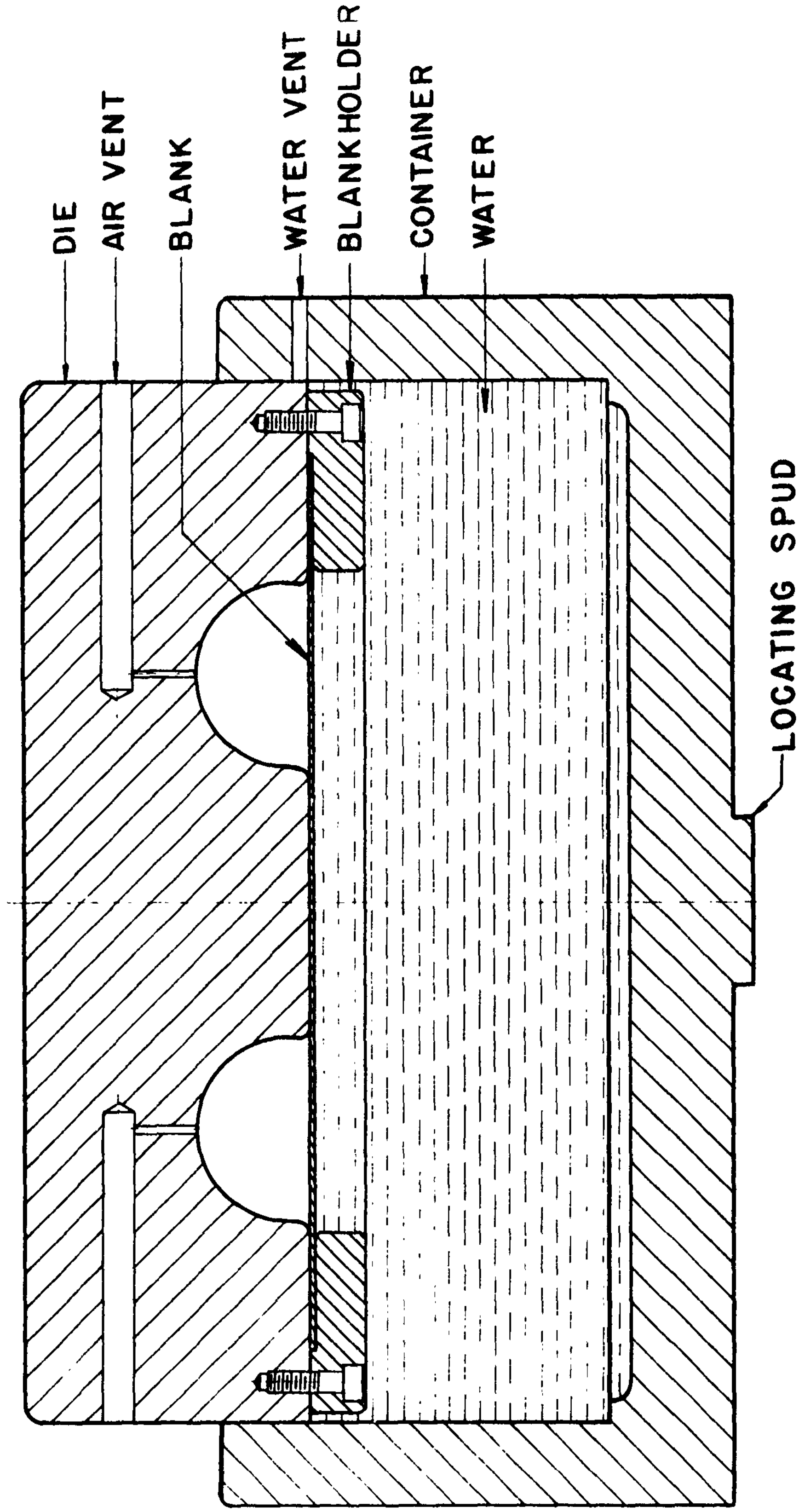


FIGURE 9



DIE (MOUNTED ON RAM) AND WATER CONTAINER(ON BOLSTER)

FIGURE 10



WATER FORMING TOOLING

FIGURE 11

SAFETY HAZARDS

The test programs described in the first part of this report were conducted with an existing high energy rate metal forming machine located in the laboratory of the Advanced Products Department of General Dynamics Corporation in San Diego, California.

A careful study of the safety hazards was made before the test programs were started. This study was based on the experience gained with the operation of high energy rate machines since 1958 and the experiences of the many commercial users of these machines.

Two possible sources of injury to personnel were discovered. The first was the possibility of the rubber pad container being burst by the internal pressure in the rubber pad and the second was the possibility of personnel being injured by the advancing of the ram of the machine while they are working on the tooling in the machine.

The first source, the rubber pad container, 4031, was eliminated by the use of a guard that was already provided on the machine and used in other experimental work performed on this machine.

It was decided that a twelve-inch (12") diameter rubber pad was to be used and this, of course, determined the inside diameter of the rubber pad container. The outside diameter of the container, sixteen and one-half inches (16-1/2"), was determined by the space available in the working area of the laboratory machine. As a result, the walls of the container were thinner than would normally be used. A stress analysis showed that the container would be safe if made of 4340 Steel heat-treated to Rockwell C 36-40. It was advisable, however, to make use of the guard already provided.

This guard is mounted on wheels running on rails and is easily pulled into place, covering the work area. A portion of the guard may be seen on Figure 7.

The second hazard, the moving ram, is largely eliminated by the simple, but exact, control system built into the machine.

When the ram is retracted, the work is done by a hydraulic fluid and this fluid, after it has recompressed the gas used to actuate the ram on the operating stroke, is trapped behind the piston on the ram, thus effectively preventing movement of the ram until the operator so desires. With the machine in this condition, although the energy is available in the compressed gas, it is safe to work in the space between the ram and the bolster. The ram cannot advance until the trapped oil is deliberately removed and the machine made ready to operate.

There are times when it is desirable to advance the ram at low speed, for instance, when the ram is used to press the rubber pad into its container. When this action of the ram is desired, it is advanced by the compressed gas but its forward movement is controlled by the controlled release of the trapped oil. It is thus possible to "inch" the ram forward as slowly or as fast as is desired.

When it is desired to return the ram, this is done with the hydraulic fluid, recompressing the gas, and under the complete control of the operator.

The position of the ram, its movement forward or backward, and the speed of this movement is always under the direct control of the operator of the machine.

Since the ram can only be returned by the hydraulic fluid, this fluid is always present when the ram is returned and its presence prevents forward movement of the ram until deliberately initiated by the machine operator, and then at the speed and to the position that he desires. It was thus possible to mount the tooling in the machine, press the rubber pad into position, or remove it, to place test blanks in the machine and to remove the finished formed parts without hazard to the technician, the tooling, or the workpiece.

PHASE III - PROTOTYPE MACHINE PRELIMINARY DESIGN AND SPECIFICATIONS

The work to be done in this phase of the contract may be outlined as follows:

I. Preliminary Design Sketches and Layouts.

  A. Analysis of tooling and rubber pad position.

    1. Tooling in upper position, rubber pad in lower.

    2. Tooling in lower position, rubber pad in upper.

II. Specification of Prototype Machine, Including But Not Limited To:

  A. Energy source

  B. Control of machine

  C. Materials used in machine

  D. Design stress factors

  E. Tooling Requirements (see also I.A., above)

    1. Space requirements

    2. Mounting methods

    3. Workpiece handling and holding

III. Cost Estimate

  A. Engineering Costs

    1. Preliminary analysis

    2. Preliminary layouts

    3. Design layouts

    4. Stress analysis

    5. Detail drawings

    6. Checking

    7. Reproduction

    8. Liaison

9. Purchase order preparation

10. Bid evaluation

11. Testing of prototype

12. Test evaluation

13. Preparation of report

B. Procurement Costs

1. Vendor surveys

2. Fabricated parts

3. Purchased parts

4. Quality control

   a. At vendor

   b. At DYNAPAK Facility

C. Erection Costs

1. Assembly

2. Quality control

3. Installation for testing

D. Testing Costs

1. Instrumentation

2. Operation

E. Shipping Costs

1. Crating

2. Freight

BIBLIOGRAPHY & REFERENCES

1. "Principles and Methods of Sheet-Metal Fabricating", George Sachs, Reinhold Publishing Corporation, New York (1956)

2. "The Design and Application of Polyurethane Tooling", Robert E. Moyer, Paper SF 62-20, American Society of Tool and Manufacturing Engineers

3. "Buckling Limits in Contour Forming", William W. Wood, "The Tool Engineer", February, 1957

4. "Final Report, A Critical Review of High Energy Forming", W. W. Wood, Report No. AER/ME/OR-5-3, Chance Vought Aeronautics, 19 January 1960

5. "Theoretical Formability", W. W. Wood, R. E. Goforth, R. A. Ford, "Product Engineering", 16 October 1961

6. "Theoretical Formability", Vol. II, "Application", W. W. Wood, et al, AF 33(616)-6951, Project 7381, ASD TR 61-191 (II) August, 1961

7. "Detailed Procedure for Formability Test", Manufacturing Development Department, General Dynamics-Convair, San Diego, California

8. "Determining Springback", R. G. Sturm, B. J. Fletcher, "Product Engineering", October, November, 1961

9. "High Energy Rate Metal Forming", Final Technical Engineering Report, F. C. Pipher, G. N. Rardin, W. L. Richter, Lockheed Aircraft Corporation, California Division, AF 33(600)-35543, AMC Project 7-588, AMC TR 60-7-588, October, 1960.

10. "Recent Developments in Explosive Forming at Grumman Aircraft", Arthur Wikesser, Jr. ASTE Paper Number 229, Volume 59, Book 2, 1959

11. "Propane Booster Project Record File", Advanced Products Department, General Dynamics Corporation, San Diego, 1958.

12. "Explosive Forming", MRS 55-144, Interim Report, General Dynamics-Convair, San Diego, California, December, 1955

13. "Explosive Forming" MRS 55-144, Interim Report, General Dynamics-Convair, San Diego, California, June, 1956

14. "Explosive Forming", MRS 55-144, Final Report, General Dynamics-Convair, San Diego, California, December, 1956

15. "Development of Production Application for Convair HYGE Machine", RDMA 7-2, Final Report, General Dynamics-Convair, San Diego, California, December, 1957

16. "High Velocity Impact Metal Forming and Shaping", MRS 56-213, Final Report, General Dynamics, San Diego, California, December, 1957

17. "Progress Report, Trapped Rubber Forming Die, MCAC IJ 8229", Report 1, Tool Design Group, General Dynamics, San Diego, California

18. "Multipurpose Rubber Die (Trapped Rubber Blanking and Piercing)", PR 337, PR 346, General Dynamics, San Diego, California, April 1961

19. "New Concept of a Fast-Moving Pneumatic Impact Ram", A. A. Ilyooshyn, P. M. Ogilov, News Bulletin of USSR Science Academy Technical Department (Translated from Russian by J. Frankowski), File Code: TAR 61-T-26

20. "Design of a Large, Two-Stage, Light-Gas Model Launcher", W. B. Stephenson, D. E. Anderson, Contract AF 40(600)-800, AEDC-TR-61-6, June 1961

21. "Chipless Machining", Charles H. Wick, The Industrial Press, New York, 1960.

22. "Development of High Loading Rate Testing Machine for Picatinny Arsenal Nuclear and Advance System Laboratory, Dover, New Jersey", Quarterly Progress Report Q-5, Robert E. Sebring, Hesse-Eastern Division, Flightex Fabrics, Inc., Contract No. DA-19-020-501-ORD-5164, May, 1961

23. "High Energy Impact Capability of the Temco Hot Gas Actuator Test Installation", Temco Electronic & Missiles Company, Dallas 22, Texas

24. Letter, J. A. Kline, to Headquarters, ASD, AFSC, Wright-Patterson Air Force Base, Ohio, 11 September 1961

25. "Stress-Corrosion Cracking-A Nontechnical Introduction to the Problem", Warren E. Berry, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio, DMIC Report 144, OTS PB 151103, January, 1961

26. "Environmental and Metallurgical Factors of Stress Corrosion Cracking in High Strength Steels", DMIC Report #151, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio, April, 1961

27. "Stress Corrosion of Steels for Aircraft and Missiles", E. H. Phelps, A. W. Loginow, Applied Research Laboratory, United States Steel Corporation, Morroeville, Pennsylvania

28. "A Medium-Speed Tensile Testing Machine", A.G.H. Andersen, Technical Report No. WAL TR 020/14, Watertown Arsenal Laboratories, Watertown Arsenal, September, 1961

29. "Pressworking '62 Features Low-Cost Tooling", Daniel B. Dallas, "The Tool and Manufacturing Engineer", February, 1962.

30. "Theoretical Formability", Vol. I, "Development", W. W. Wood et al, AF 33(616)-6951, Project 7381, ASD TR 61-191(I), August, 1961

RUBBER PAD SOURCES

The following companies were requested to bid on suitable rubber pads:

1. Acushnet Process Company
   776 Belleville Avenue
   New Bedford, Massachusetts

2. Dayton Rubber Company
   2342 West Riverview Avenue
   Dayton 1, Ohio

3. Elkhart Rubber Works
   1630 Oakland Avenue
   Elkhart, Indiana

4. B. F. Goodrich
   500 South Main Street
   Akron 18, Ohio

5. Goodyear Tire & Rubber Company
   1144 East Market Street
   Akron, Ohio

6. Kirkhill Rubber Company
   300 East Cypress Street
   Brea, California

7. Los Angeles Standard Rubber Company
   1500 East Gage Avenue
   Los Angeles 1, California

8. G. A. Mosites Company
   2720 Tillar Street
   Fort Worth 2, Texas

9. Pioneer Rubber Company
   245 Tiffin Road
   Willard, Ohio

10. Rubbercraft
    1800 West 220th Street
    Torrance, California

11. Standard Die Set Company
    1485 Elmwood Avenue
    Providence 7, Rhode Island

12. Thiokol Chemical Corporation
776 North Clinton Avenue
Trenton, New Jersey

13. U. S. Rubber Company
1 Market Street
Passaic, New Jersey

DISTRIBUTION LIST

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Contract: AF 33(600) - 43035
Project Number 7-848

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Commander Air Research & Dev. Center Attn: C. W. Kniffin Baltimore, Maryland	14
Aerospace Industries Assoc. Attn: J. A. Maurice Technical Services 7660 Beverly Boulevard Los Angeles 36, California	15
Aerojet-General Corporation Attn: K. F. Mundt, V-Pres., Mfg. 6352 N. Irwindale Avenue Azusa, California	16
General Motors Corporation Allison Division Attn: E. D. Berlin, Head of Exp. Process Dev. P. O. Box 894 Indianapolis 6, Indiana	
Bell Aircraft Corporation Niagara Falls Airport Attn: Ralph W. Verrial, Mfg. Production Engrg. Buffalo 5, New York	18
Bendix Products Division Bendix Aviation Corporation Attn: A. J. Walsh, Staff Asst. 401 Bendix Drive South Bend, Indiana	19

The Boeing Company 20
Attn: F. P. Laudan
V-Pres., Mfg. Hq. Office
P. O. Box 3707
Seattle 24, Washington

The Boeing Company 21
Attn: W. W. Rutledge
Mfg. Manager
Wichita 1, Kansas

Cessna Aircraft Company 22
Military Aircraft Division
Attn: C. C. Hendricks
Mfg. Engineer
Wichita, Kansas

Chance Vought Aircraft, Inc. 23
Attn: Chief Librarian
Engineering Library
Dallas, Texas

Cleveland Pneumatic Ind., Inc. 24
5781 East 77th Street
Cleveland 5, Ohio
Attn: Fred W. Olsen
Asst. Prog. Planning Dir.

Convair, Div. Genl. Dynamics Corp. 25
Attn: F. A. Monahan, Mgr.
Mfg. Develop. & Proc. Spec.
Zone 190-00
San Diego 12, California

The Boeing Company 26
Aerospace-Division
Attn: B. K. Bucey, Asst. To
V-Pres., Manufacturing
P.O. Box 3707
Seattle 24, Washington

Convair, Div. Genl. Dynamics 27
Attn: A. T. Seeman, Chief of
Engrg. Mfg.
P.O. Box 1011
Pomona, California

Convair, Div. Genl. Dynamics 28
Attn: R. A. Fuhrer, Chief
Manufacturing Engr.
P.O. Box 748 (Mail Zone T34)
Fort Worth, Texas

Curtiss-Wright Corporation 29
Attn: S. B. Kurzina, Jr.
V. Pres. & Dir. Mfg. Engrg.
Wood Ridge, New Jersey

Curtiss-Wright Corporation 30
Propeller Division
Attn: L. H. Wurster, Works Engr.
Caldwell, New Jersey

Douglas Aircraft Co., Inc. 31
Santa Monica Division
Attn: N. H. Shappell, Works Mgr.
Santa Monica, California

Douglas Aircraft Co., Inc. 32
Attn: O. L. Rumble, Tooling Mgr.
3855 Lakewood Boulevard
Long Beach 8, California

Douglas Aircraft Co., Inc. 33
Attn: Jess L. Jones, Genl. Mgr.
2000 N. Memorial Drive
Tulsa, Oklahoma

Fairchild Aircraft & Missiles Div. 34
Fairchild Airplane Corporation
Attn: A. D. Jairett, Mgr.
Tool Engrg. & Mfg.
Hagerstown 10, Maryland

General Electric Co. 35
Aircraft Gas Turbine Division
Attn: Mgr., Mfg. Engrg.
Cincinnati 15, Ohio

General Electric Company 36
Missile & Space Vehicle Div.
Attn: L. I. Chasen
3198 Chestnut Street
Philadelphia 4, Pennsylvania

Goodyear Aircraft Corp. 37
Attn: R. C. Williams, Mgr.
Administrative Engrg.
1210 MassilonRoad
Akron 15, Ohio

Grumman Aircraft Engrg. Corp. 38
Attn: Wm. J. Hoffman, V-Pres.
Manufacturing Engrg.
Bethpage, L. I., New York

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Aircraft Division
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El Segundo, California

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Grand Rapids, Michigan
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Santa Monica, California

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Marietta, Georgia

Lycoming Division 49
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Stratford, Connecticut

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Ch. Ind. Engr.
P. O. Box 516
St. Louis 66, Missouri

The Martin Company 53
Attn: Chief Librarian
Engrg. Library
Baltimore 3, Maryland

North American Aviation, Inc. 54
4300 East Fifth Avenue
Columbus 16, Ohio
Attn: M. E. Fisher, Supv.
Mfg. Develop. Plant Engrg.

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Attn: Latham Pollock
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Internation Airport
Los Angeles 45, California

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United Aircraft Corporation
East Hartford, Connecticut

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Stratford, Connecticut

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Temco Aircraft Corporation 66
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505 King Avenue
Columbus 1, Ohio

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Washington 25, D. C.

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2139 Wisconsin Avenue, N. W.
Washington 7, D. C.
Attn: Ludlow King, Exec. V-Pres.

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564 Derbyshire Road
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The Cincinnati Milling Machine Company 94
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Cincinnati 9, Ohio

Armour Research Foundation of
Illinois Institute of Technology 95
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Chicago 16, Illinois

Vought Aeronautics, Inc. 96
Attn: Mr. W. W. Wood,
Mfg. Res. Proj. Engr.
P. O. Box 5907
Dallas 22, Texas

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